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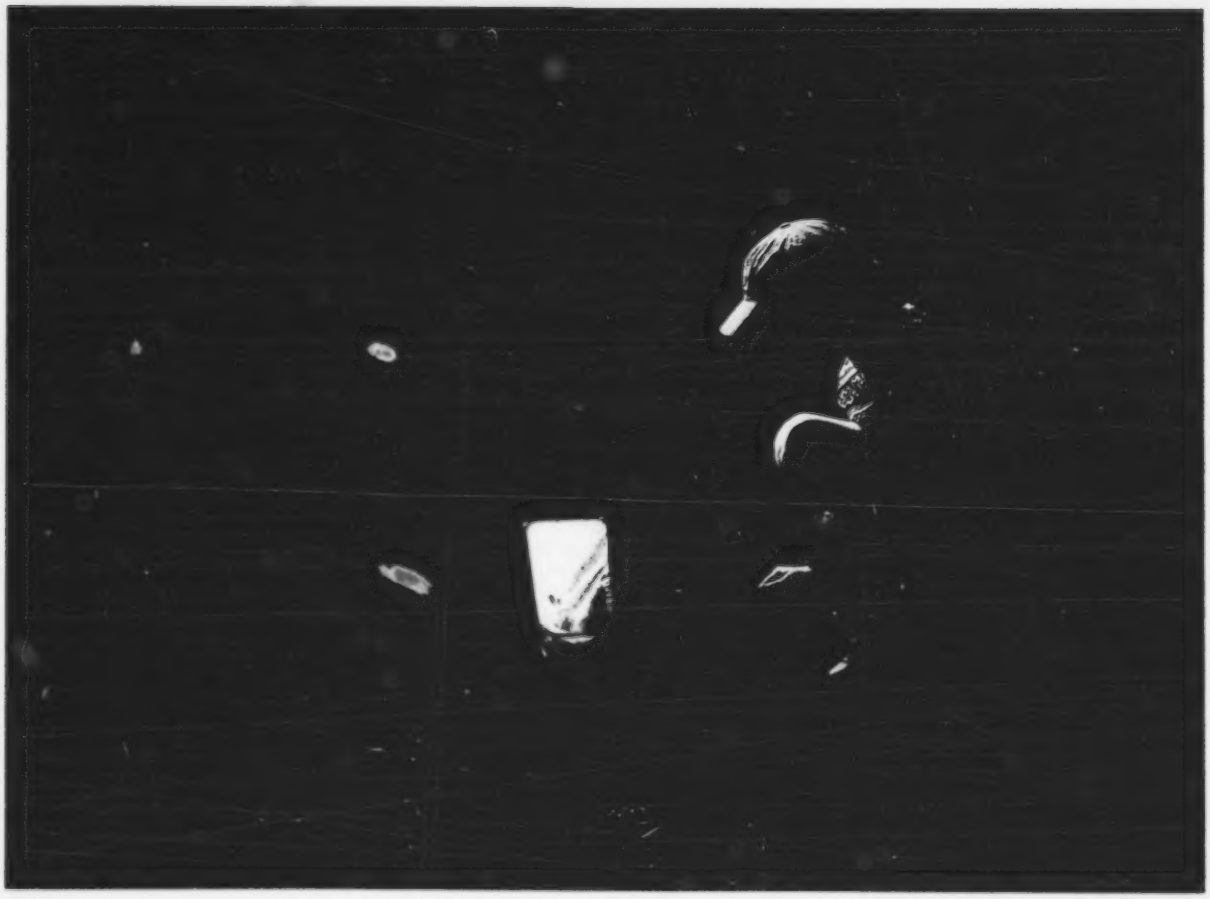
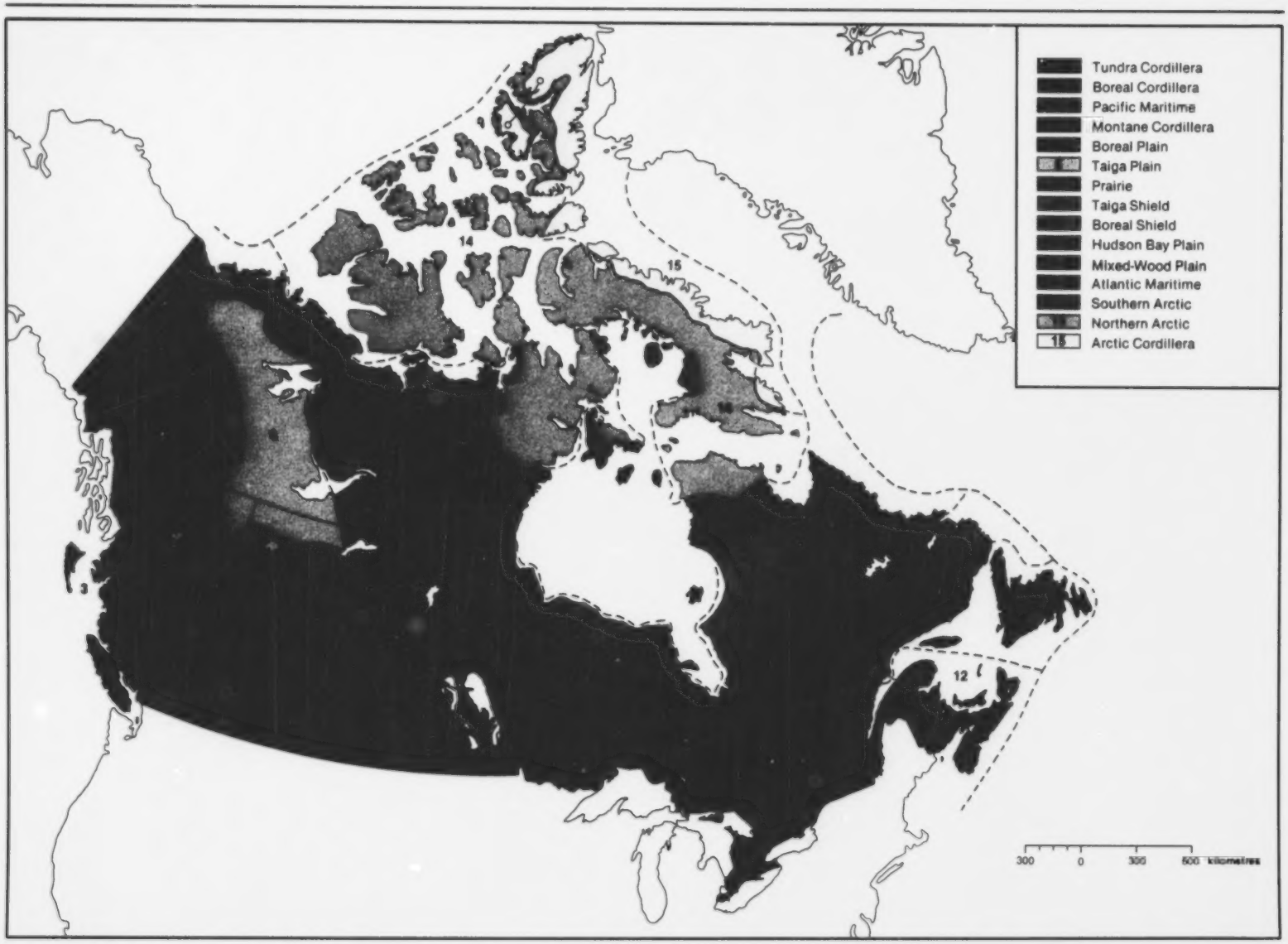
State of the Environment Report for Canada



Canada

Ecozones of Canada



Source: Environment Canada, Lands Directorate, 1982.

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State of the Environment Report for Canada

Peter M. Bird
Environment Canada

David J. Rapport
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May 1986

The following symbols and abbreviations are used in the tables in this report:

— no data

NA data not available

.. trace quantity too small to be expressed

a blank space denotes 'not applicable' or no interaction between the item on the vertical and the item on the horizontal axis of the table

* data confidential under the *Statistics Act*

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Preface

This is the first comprehensive report ever undertaken on the State of the Environment for Canada. It is a major accomplishment. Although much of the credit must go to Dr. Peter Bird and Dr. Dave Rapport, the two authors who pioneered this work, they would be the first to recognize the contributions of the many individuals who, through their technical assistance and moral support, made this report possible.

The report pieces together a wide selection of available information in such a way that patterns of environmental change can be identified and understood. It describes the condition of our farmlands, forests, waters, wildlife and other natural resources Canadians hold in common.

The organization, assessment and condensation of the information into a useful resource document were no mean task and demonstrate the strong commitment of those involved. The authors faced the problem of interpreting data collected by many agencies for purposes other than environmental reporting. Subjective judgements in the choice of approach, in data reconciliation and evaluation, and in the analysis of the available data are inevitable in an exercise such as this.

Although this is a major step in environmental reporting, it is only the beginning. The challenge ahead is to develop a process for producing regular environmental reports of this nature and to use that information to make better decisions about our use and management of the environment. A collective effort by governments, industry, labour and, no less important, individuals is required to ensure that we pass on a healthy and productive environment to future generations.

Foreword

Canadians, individually and collectively, interact with their environment, whether they live in urban centres and are employed in commercial-industrial complexes, or are residents of rural areas engaged as individual resource-based entrepreneurs in their woodlots, fishing boats, gardens or farms. To sustain human life is to interact with the environment. Whether we keep warm by burning wood, gas, coal or oil, we change the composition of the world's atmosphere and alter the resource base in the process. When we drive to work, or to the wilderness, we contribute our portion of residues to the land, air and water. The food we eat, and all the material we use for clothing, shelter and the equipment for daily activities, come directly and indirectly from natural resources. Our extractions and contributions represent a part of the sum total of the human effects on the global environment.

Concern about the environment and understanding of its importance to human well-being increased rapidly in Canada, and in many other countries, during the past two decades. Rapid expansion of energy use and increases in the standard of living brought incidents of severe pollution and damage to the land and water, leading in the early 1970s to outbursts of concern and confrontation, and to a degree of confusion in all sectors of society. The evidence that in some areas the quality and productivity of the environment had been and were being degraded led to fears that we would push use of our environment too far — and to the realization that it is possible to overstep the boundary of sustainable development without knowing it until it is too late. Anxiety bred a desire for reliable knowledge: how fast and to what extent were human activities causing environmental change, and how deleterious were those changes to individuals, to the economy, and to the life support capabilities of the environment?

Reporting to the public on changes in the condition of the environment and on the implications of those changes for Canadians is an essential element in the overall response to the very real concerns about the impact of our activities on the environment, as well as to the demand for reliable measurement of changes that are taking place. State of the environment reporting also serves as a multi-faceted mirror that will help us to gain a better perspective on ourselves and our land — the beauty spots as well as the scars. While the reports may record losses, they also provide us with an inventory of what we now have and a basis for measuring gains and improvements in the future. Thus they will provide a basis for planning future use

and management of environmental resources. We hope that this reporting will strengthen the commitment of Canadians to sustainable development — an approach to extraction of resources and to other uses of the environment based on the belief that drawing current benefits from the environment should not result in degradation of environmental quality for future generations.

This first report on the state of the Canadian environment is both a major achievement and a starting point. It has taken a great deal of dedicated effort to develop the concepts and to test their validity on a scientific and practical basis; to assemble and interpret data; and to bring the first report into print. While the report is valuable in itself, its greatest value will be demonstrated and appreciated in the future as this report and the data it contains serve as a baseline for subsequent reports and for systematic measurement of changes in the quality and character of our natural environment.

There is a widespread demand for the type of information contained in this state of the environment report. In recent years the demand has grown and spread from environmental organizations and individual Canadians to all sectors of society, including business and industry, labour, research and educational institutions, and the various levels of government. While the data on which the report is based existed in the past, they were not readily accessible, and they were not related, interpreted and presented in an informative manner geared to the needs of the users of state of the environment data. In the Council's experience, through discussions with a variety of individuals and groups and in the personal experience of Council members, there is such a range and variety of needs — from generalized nation-wide data to information on specific issues or areas — that it appears most unlikely that this initial report will meet fully the needs of all users. It has the inestimable virtue, however, of being a beginning, a first edition that can be improved in the future in response to criticisms and suggestions from individuals and groups of users.

Council commends the authors, Dr. Peter Bird and Dr. David Rapport, and others who played a variety of supporting roles, for a major achievement. They faced a formidable task in capturing, between two covers, such an enormous and complex subject as a comprehensive, synthesized statement on the environment of all parts of Canada. Some of the obstacles were conceptual; others concerned the inadequacy or incompatibility of data, most of which had been collected for purposes other than assessing the state of the environment; and, finally, there were the obstacles of maintaining scientific credibility while making value judgements and of relating financial and natural resource information in different time periods and geographic regions. There were variations in the amount and quality of data available, and therefore coverage of some subjects could not be as complete and accurate as the coverage of others. These inadequacies can only be overcome as more complete, more relevant, and better co-ordinated data are collected for future editions. The processes for collecting, interpreting and presenting the data also need to be examined to ensure that they are effective, avoid duplication, and produce accurate, representative and useful information.

The document reports on the basis of fifteen terrestrial ecozones and four aquatic ecosystems. Given the vastness and diversity of Canada, this is a logical but innovative approach. Although, at times, political boundaries had to prevail, wherever the data permit they are assembled and compared on an ecozone basis. This approach allows characteristics of the environment to be compared within ecosystems over time and between one ecozone and another at any one time. It also makes possible, for the first time, an examination of an ecosystem based not on a general description and subjective interpretation, but on quantitative data of physical, biological and dynamic response characteristics. Thus the extent and seriousness of potential or actual environmental change, or the amount and condition of a specific natural resource and its relation to other resources, may be identified in a way not previously possible.

The Canadian Environmental Advisory Council was not directly responsible for preparation of the report, but, over the years, it has drawn attention to the need for systematic collection and dissemination of information on the state of the environment. Council gave support first to pioneering work on environmental indices and, subsequently, to development of concepts for state of the environment reporting. Members reviewed successive proposals for this report and, more recently, draft sections of the report itself. The importance that Council attaches to this activity is indicated by the following statement, which was part of a recent commentary by Council on priorities for Environment Canada: "...public reporting on a regular basis regarding the state of the environment so that the private sector, other departments and governments, organizations and institutions, and the general public are aware of changes and trends in the condition of their environment. A regular state of the environment report should be institutionalized as a required output of the department."

The environment is the foundation on which we base all economic and social activity — in fact, it is the base of life itself. In Council's view, systematic, comprehensive, regular reporting on the state of the environment is no less indispensable to the country than a statement of national accounts or the cost of living index; it is as essential to individual Canadians as a bank balance statement or a regular medical examination. All provide a basis for assessing our condition as a nation and as individuals, and for planning our future.

— Canadian Environmental Advisory Council

Acknowledgements

The preparation of this prototype report could not have been undertaken without the strong support and guidance of a large number of individuals from a wide variety of organizations.

The initial steps were taken at an ad hoc meeting of experts convened in March 1981 by Dr. J.S. Maini of Environment Canada and Mr. A.M. Friend of Statistics Canada. The experts were drawn from university and governmental offices and they provided initial guidance concerning such matters as need, purpose, structure, content and sponsorship. This group urged the adoption of an ecosystem approach using data from many sources (federal, provincial and non-governmental).

Proposed outlines for the report format were developed and modified throughout the following three years as consultations proceeded and as actual data were gathered and analyzed.

Individuals far too numerous to list provided information of one kind or another. We are no less indebted to those who contributed but whose names are not specifically mentioned here.

To give some indication of the nature and extent of the assistance we received throughout this project, there are several groups that we would like to mention.

Among the non-governmental experts who provided either overall comment or information concerning specific aspects of the report are Dr. G. Baskerville, Dr. D.A. Chant, Dr. S.A.N. Conover, Dr. R.T. Coupland, Dr. B. Dancik, Dr. G. Francis, Dr. F.K. Hare, Mr. M. Hummel, Dr. O.L. Loucks, Dr. P.A. Larkin, Dr. T. Munn, Dr. J.S. Rowe, Dr. W. Ricker, Dr. C. van Netten, Dr. R. Wallace, and Dr. W.G. Wellington.

There were also a number of commissioned background studies related to various aspects of the report. These included

— the initial proposals for an ecological zonation of Canada by Hunter and Associates, Toronto;
— a personal interview survey of a cross-section of organizations thought to be interested in state of the environment reporting by P. Timmerman, University of Toronto;
— a study of agro-ecosystems in western Canada by C.F. Bentley et al., Edmonton;
— a study of agro-ecosystems in eastern Canada by E.E. Mackintosh of Ecological Services for Planning, Guelph, Ontario;
— a study of forest ecosystems by L. Sayn-Wittgenstein of Dendron Resource Surveys, Ottawa;

- a study of wildlife ecosystems by Wm. Thurlow and Associates, Environmental Control Consultants, Ottawa;
- an historical and international perspective on wildlife by A. Keast, Queen's University;
- a study of the Great Lakes aquatic ecosystem by H.A. Regier, University of Toronto;
- a study of arctic aquatic ecosystems by M.A. Dunbar, McGill University;
- a study of east coast aquatic ecosystems by J.M. Anderson of J.M. Anderson Associates, St. Andrews, New Brunswick;
- a study of governmental environment-related expenditures by S. Macenko, Ottawa;
- a study of non-governmental organizations by the National Survival Institute, Ottawa;
- a study of non-governmental environment-related expenditures by Wm. Thurlow and Associates, Environmental Control Consultants, Ottawa;
- a study of global environmental concerns by S. Miles, Toronto; and
- a study of the environmental perceptions of Canadians by A. Whyte, University of Toronto.

Consultations were also held with representatives of a number of government departments and agencies at both the federal and provincial levels. With respect to provincial contacts, presentations describing the general nature of the project were made at two successive annual meetings of the Canadian Council of Resource and Environment Ministers, and specific contact was established with most provincial departments of the environment and with provincial departments responsible for lands, parks, agriculture, forests and other resources. At the federal level, consultations involved representatives of various departments and agencies, usually through a specified co-ordinating office in each department. These included the Department of Agriculture (Institutes and Program Co-ordination Directorate, Research Branch), the Atomic Energy Control Board, the Department of Energy, Mines and Resources (Office of Environmental Affairs), the Department of External Affairs (Legal Affairs Branch), the Department of Fisheries and Oceans (Fisheries Research Directorate), the Department of Indian Affairs and Northern Development (Northern Environment Branch), the International Joint Commission (Canadian Section), the Department of National Health and Welfare (Environmental Health Directorate and Food Directorate), the National Research Council (Environmental Secretariat) and the Department of Transport (Government, Industry and International Relations).

Within Environment Canada, data were provided by most operational units, sometimes directly and sometimes through a co-ordination centre. For example, data were supplied by the Atmospheric Environment Service, the Environmental Conservation Service (Inland Waters Directorate, Canadian Wildlife Service and Lands Directorate), the Environmental Protection Service (largely through Environmental Interpretation), the Canadian Forestry Service — now with Agriculture Canada — (Forest Research and Development), and Parks Canada (Program Planning and Analysis Directorate). Special mention should be made of the contributions by Mr. E. Wiken of the Lands Directorate in connection with the development of the ecozone framework.

Within Statistics Canada, data were provided by a number of different units. These data were either co-ordinated or processed by the research staff of the Environment Statistics Program of the Office of the Senior Adviser on Integration. Special mention should be made of the contribution of the Geography Division in developing programs to retrieve Census data by river basin and ecozone, the Geocartographic Unit for computer mapping, and the Agricultural, Health, and Manufacturing and Primary Industries Divisions for efforts to recast their data for our special needs.

The authors wish to pay special tribute to the untiring efforts of their respective support staffs. At Environment Canada, the majority of the initial word processing work was most capably handled by Jackie Archambault, and later work by Lynn Woodill and Pauline Briand. In Statistics Canada Elizabeth Scott devoted many hours to preparing and revising the manuscript, and Marlene Coulas cheerfully carried out the many small jobs that kept this project from falling apart.

Finally the authors wish to acknowledge the contribution of Anthony Friend in editing the manuscript with the assistance of Infolink Consultants and of Peter O'Hara, who managed the final task of bringing the Report into print, with the able assistance of Darrell Piekarz. The text, charts, and layout were produced by Expression Communication Associates of Ottawa.

1

Introduction: Setting the Stage

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ENVIRONMENT AND ECONOMIC DEVELOPMENT

The state of the environment, and its rate of change, are of fundamental importance to a nation's long-term well-being. Canada has benefited enormously from its vast natural resources. Forests, fisheries, agriculture, fur-bearing mammals and minerals have been the backbone of its economic development.

Until relatively recently, the desire for continued improvements in the economic quality of life has not been accompanied by a sufficient appreciation of the possible adverse environmental effects of economic development. This situation is changing; nowadays more and more people are aware that sustainable economic development depends upon sound environmental management.* Concerns about conservation, preservation and environmental quality are now finding their way into economic calculations. Sound economic planning and sound environmental management do not, in this light, conflict; rather, they reinforce each other.

ENVIRONMENTAL REPORTING

Reporting on the state of the environment is not new. Several countries, in particular the United States and Japan, have published annual reports on environmental quality in recent years. In fact, among the 24 member countries of the Organization for Economic Co-operation and Development (OECD), some 16 countries have produced state of the environment reports or compendiums of environmental statistics. These reports vary considerably in approach, subject matter and quality of the supporting data.

In 1979, the Environment Committee of the OECD released its first report on the state of the environment in member countries. A second report was prepared for the meeting of OECD environment ministers in June 1985.[5,6] These reports not only described the state of the environment but also identified the pressures of human activity (e.g., agriculture, energy, industry, transport) that alter the state of environmental components (air, water, land, living resources) and the nature of the corrective measures undertaken by governments and industry in response to these changes.

In 1980, the International Union for the Conservation of Nature and Natural Resources, the United Nations Environment Program (UNEP), and the World Wildlife Fund joined hands in the publication of the World Conservation Strategy.[4] The aim of the Strategy was to help advance the achievement of sustainable development through the conservation of living resources. It explains the contribution of living resource conservation to human survival, identifies important conservation issues, and proposes effective ways of achieving the aims of the Strategy.

In 1982, UNEP published its first major review of the world environment.[2] This report covers global environmental concerns, considering the changing biosphere in the context of human and social systems (e.g., topics relating to industrial and urban environments).

Environmental Reporting in Canada

Few efforts have been made to provide a comprehensive assessment of the state of the Canadian environment. Existing reports are regional and topical rather than national and comprehensive.*

Various components of government departments produce, on occasion, comprehensive studies of their particular area of concern; an example is "Stress on Land", published by Environment Canada. Reviews of topical issues, such as those published by the Canadian Environmental Advisory Council, cover such subjects as nuclear power and the environment, ecotoxicity and endangered species. Although not an established procedure, reports appear once in a while on local or regional environmental conditions, a good example being a report entitled "Environmental Quality in the Atlantic Provinces", prepared by the regional office of Environment Canada.**

Several years ago, Environment Canada examined the possibility of producing a general index of environmental quality for Canada.[3] This approach was eventually abandoned, in part because of the inadequacy of data and the sheer difficulty of establishing a meaningful statement on the average state of the environment.† Recently, however, Environment Canada produced a report summarizing the current status of environmental issues in Canada.[1]

These actions reflect, in part, a desire among the environmentally concerned public for a national statement of conditions and trends in the Canadian

*"... in Canada, with its rich resource heritage, there is no conflict, in the long term, between the stewardship, preservation and enhancement of the natural resource base and the growth prospects for the traditional resource industries. Consequently, we perceive a vital need to integrate environmental decisions and decisions related to economic development." The Royal Commission on the Economic Union and Development Prospects for Canada, *Report*, Volume 2 (Ottawa: 1985).

*To obtain further information on published material on environmental reporting in Canada, contact the Library Service Branch, Environmental Canada, Ottawa K1A 1C7.

**A second report is currently being prepared.

†One of the characteristics of environmental data is that they relate to physical, biological and chemical properties and are, therefore, necessarily expressed in a variety of units, with little possibility of conversion, one to another. This has been a source of frustration to decision makers desiring a bottom line to questions like "is the environment improving or not?".

There has been a continuing search by some workers to simplify this situation — to bring these various aspects into a common index of environmental quality or, alternatively, to convert the various environmental aspects to dollar values to provide a basis for more conventional cost-benefit analysis.

We have not followed this approach, nor do we believe that such a simplification would be particularly helpful in describing or understanding environmental change. In fact, judgements on the state of the economy rest on individual trends in such diverse factors as employment rates, inflation, production, balance of payments, national debt, etc. Obviously, it is not possible to combine these aspects in any single meaningful index. A similar situation prevails with regard to the development of a single environmental quality index.

environment. A survey of a broad range of non-governmental organizations found widespread support for a report on the state of Canada's environment.[11]

Statistics Canada and Environment Canada, in partnership, have responded to this need by undertaking the development of this prototype State of the Environment (SOE) Report for Canada. This report is designed to provide a comprehensive overview of environmental conditions and trends in Canada, with the specific intention of

- presenting a macro-picture of environmental conditions and recent trends based on up-to-date scientific assessments;*
- providing a baseline against which future changes can be judged;
- providing an opportunity for observing where additional research or preventive measures could be particularly effective; and
- contributing to a wider understanding of interrelationships between environmental conditions and socio-economic activities.

In presenting this report, we are focusing, quite naturally, on environmental conditions and trends rather than on economic or social conditions. We have not, however, taken an environmental advocacy position, nor have we tried to defend any policies or programs. On the contrary, our aim has been to prepare a broadly based, objective evaluation of environmental conditions and trends in Canada. We recognize that almost all human activities confer some benefits to society and that a good many environmental changes — for example, clearing forests for agriculture and human settlement — have enormous economic benefits. A balanced view of economic development and environmental change must keep a firm grasp on the positive, as well as the negative, aspects of various actions.

This is intended to be the first in a series of periodic reports on the state of the Canadian environment. It is directed to those individuals in government, industry and the academic community that might profit from an overall perspective on conditions and trends in the environment and on various stresses or influences thought to be responsible for environmental change. The report is also directed to those concerned citizens who, through their personal commitments and activities, seek comprehensive information about the state of the Canadian environment.

APPROACH AND METHODOLOGY

The basis for the SOE Report is the stress-response conceptual model. This considers a variety of stress factors (e.g., pollution loadings, land use changes and resource exploitation) and ecosystem responses (e.g., changes in productivity, species composition and disease incidence).*

Because Canada is so large and ecologically diverse, it is impossible to regard the country as a single ecosystem. Furthermore, the nature and importance of stress factors vary greatly from one part of the country to another. It was therefore desirable to develop some form of regional analysis as part of the framework for the report.

Because jurisdictional boundaries do not provide a rational basis for a discussion of the environment, we undertook to develop a new geographical framework defining 15 terrestrial ecozones and 4 aquatic ecosystems. The terrestrial ecozone boundaries define very broad natural systems, taking into account such factors as physiography, vegetation, soil and/or surface materials, and climate. A considerable amount of computer-based data has been compiled for these ecozones. In many cases, however, it has not been possible to convert existing data to suit the new geography, and so the reader will find a mixture of jurisdictional, river basin and ecozone-based data sets in the report. These inconsistencies are the inevitable result of the introduction of a new geographical basis for environmental reporting, but they should disappear gradually as the ecozone system framework becomes more widely known and accepted.**

In choosing our topics and data, we were guided by a number of factors:

1. the advice of consultants and other experts concerning conceptual design, major environmental issues and sources of environmental data;
2. the existence of data that would enable us to quantify conditions and trends that have direct relevance to key environmental concerns; and
3. the desirability of providing national coverage, preferably in a form that also permitted analysis of time trends and regional differences.

We must caution readers on two points. First, the available data vary in quality in terms of compatibility and accuracy. For example, it was often necessary to combine data gathered by different agencies or for different purposes, where the time scales and/or analytical methods were different. Second, environmental data gathering is a continuing activity, and new reports are constantly becoming available. Some of

*Most environmental data are collected for specific sites and time periods. Our challenge was to find ways of using such micro-data to create a macro-picture — for a region or, in some cases, for the country as a whole. Data have been drawn from a wide variety of sources. In some cases, special compilations not previously available were undertaken; in other cases, we have drawn from the relatively few studies involving broad overviews of environmental conditions and trends. In still other cases, data pertaining to relatively small regions have been used by way of examples of conditions that likely apply to much larger areas. These aggregations and extensions of data by inference must, of course, be treated as broad-brush efforts. In aggregating environmental data, temporally and spatially, we are aware that there are a good many methodological difficulties. As we gain experience with such treatments of data, it is reasonable to expect that more data collection efforts will be designed specifically for this purpose and, therefore, that the aggregation and interpretation of such data will improve with time.

*For a discussion of the features of the Stress-Response Environmental Statistical System, see references #7 and #8.

**Conversion of environmental and socio-economic data into ecosystems and river basin spatial units is currently being undertaken by Statistics Canada. For further information on data available in this form, contact the Environmental Statistics Program, Structural Analysis Division, Statistics Canada, Ottawa K1A 0T6. Many of these data are published in reference #10.

these reports simply extend existing data series; others provide new information or new insights. The preparation of this SOE Report was spread over several years, and although every effort has been made to update it, there is little doubt that some data will be outdated by the time the report is published. State of the environment reporting must be considered a continuing process that inevitably lags to some degree behind available information. These lags may be reduced considerably with the development of co-ordinated computer databases.

Environmental management in the early 1970s focused largely on the control and abatement of pollution. The primary concern then was usually the potential effects of pollution on human health. Experience in the field of occupational health made it somewhat easier to develop a series of guidelines and standards for various pollutants. In such circumstances, we have been able to compare existing conditions and trends with published guidelines and standards.*

With respect to ecosystem responses, however, the situation is quite different. Not only are there relatively few guidelines or standards, but there is no general agreement with respect to the key parameters to measure environmental change. We have, therefore, taken an empirical approach. By comparing attributes of ecosystems under stress with those of systems not so affected, we can begin to identify properties that reflect fundamental change.[8]

Ecosystems under stress tend to exhibit one or more of the following symptoms: impaired biological productivity;** reductions in species diversity; shifts towards the more opportunistic species; reversion to an earlier stage of ecological community development; reductions in the average size of the dominant biota; and higher disease susceptibility (except in those instances where the stress weakens the disease more than the host).

The observation of these symptoms of stress provides the basis for judgements about the conditions of specific ecosystems. For some ecosystems, we have relatively good data (e.g., changes in nutrient conditions in the Great Lakes). In many cases, however, we have had to use surrogates for more ideal indicators. In still other cases, quantitative data are lacking altogether; at best, we have anecdotal evidence of environmental change.

The relationship between conditions in the environment and causes is far from simple. The principal problem is the variety and complexity of possible interactions. The observed response, at the system level, is most often the product of a number of stresses. Each stress, if acting alone, would have its own characteristic effect (time-lag and response curve). In multiple-stressed systems, however, predictability becomes more an art than a science. Nevertheless, as experience and knowledge increase, ecologists may be able to provide an analytical framework for the development of public policy similar to the contribution social scientists are making today.

For analytical purposes, we have grouped specific ecosystem stresses into five major categories: (a) harvesting and associated technology; (b) contaminants and pollution loadings; (c) land use change; (d) the introduction of exotics (i.e., non-native species); and (e) extreme natural events such as fire or prolonged drought. This breakdown conveniently organizes a multitude of particular stresses into a few distinct human and natural activities that have a fundamental bearing on environmental transformation.

STRUCTURE OF THE REPORT

We begin by discussing the geographical framework for our report — terrestrial ecozones and aquatic ecosystems. Where possible, these areas are employed as reporting units and as a framework for much of the data compilation (Chapter 2). Then we turn to conditions and trends in renewable resource systems: agriculture, forests, fisheries (inland and marine waters), and wildlife (Chapters 3 to 6).

Then we turn our attention to human activities that are far-reaching in effect and transcend ecosystem boundaries. In particular, we document information about land use changes (Chapter 7) and contaminants in the environment (Chapter 8). The presence of environmental contaminants leads naturally to a consideration of contaminants and human health (Chapter 9).

Next we examine the response of institutions and organizations to environmental change in terms of legislation and expenditures (Chapter 10). We continue with a brief discussion on the supply of, and demand for, natural resources at the global level, as well as worldwide conditions and trends (Chapter 11). We conclude with a chapter on the environmental perceptions of Canadians (Chapter 12).

*Note that urban air pollution is treated as a human health problem in this report.

**Except in those cases where the stress results in artificially fertilizing the systems, such as enriching the nutrient content of water through waste discharges or agricultural runoff. In these cases, biological productivity may be boosted above normal levels, at least for a time. However, increases often have a host of side-effects, such as eutrophication of water systems or increasing dependence on artificial means to provide the nutrient needs of cultivated plants.

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Ecozones of Canada

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INTRODUCTION

Canada's landscape is enormously diversified, encompassing tundra, boreal forest, deciduous forest, prairie, cordillera, three major oceanic systems, the Great Lakes, inland waters and other ecosystems. A description of environmental conditions and trends across such a diverse domain hardly seems feasible or meaningful. One approach is to partition the landscape into relatively large but more or less environmentally homogeneous areas.

The primary rationale for this division is to provide a framework for describing trends and conditions within a relatively homogeneous geographical base. It would, for example, be more to the point to assess changes in natural productivity or biotic composition in context of their relevant habitat than to examine these trends for all of Canada, or even for a single province, which might encompass tundra, coastal rain forest and prairie.

CRITERIA FOR TERRESTRIAL ECOZONE CLASSIFICATION

While the classification of environmental regions is necessarily somewhat arbitrary, it can be justified on pragmatic grounds. The criteria used to determine the boundaries of these 'ecozones'* are physiography, vegetation, soils/surface materials and climate. Table 2.1 provides a brief summary of the main characteristics of each ecozone in relation to each of these criteria. The choice of dominant attribute(s) employed to identify unique ecozones is of necessity influenced by subjective judgements, tempered perhaps with growing professional experience in ecological mapping. Curiously, the dominant attribute(s) often give characteristics to the visual landscape distinguishable by even the most casual observer — the glaciated rock formation of the Boreal Shield, the treelessness of the Prairie landscape, the stunted black spruce forests typical of the tundra soils in the Taiga Plain. These distinctive land surface features play an important role in delineating ecozone boundaries and, because of the remoteness of much of Canada, they must be sufficiently outstanding to be detectable by remote sensing (i.e., air photos, satellite imagery).

The terrestrial ecozone classification distinguishes very broadly between regions — boreal, prairies, arctic and so on (see map inside front cover). These form the highest level of aggregation compatible with the ecological land classification system under development by the Canada Committee on Ecological (Biophysical) Land Classification.

An ecozone is a discrete system that has resulted from the interplay of the landform (physiography), water, soils, vegetation, climate, wildlife and various human uses. These zones are large and highly generalized and may display considerable heterogeneity. For example, in the Rocky Mountains (Montane Cordillera), the change from warm, humid valley bottoms to dry, cold peaks results in a vegetation range from dense forests to arctic tundra. This vertical stratification means that all elements of the ecozone show immense variability, except for one: the fact of being mountainous. The highly man-influenced heterogeneity in the Mixed-Wood Plain is equally striking. This region consists of mixed forests, agricultural lands, and highly urbanized/industrialized areas.

Nor is the boundary between ecozones always sharply defined. In some cases (for example, the separation of the Hudson Bay Plain from the Southern Arctic) the transitional boundary may vary in width from tens to hundreds of kilometres. Ecozones range in size from less than 200 000 km^2 (the Atlantic Maritime ecozone) to over 1 800 000 km^2 (the Boreal Shield). Only two of the regions are entirely inside a jurisdictional boundary: the Pacific Maritime (within British Columbia) and the Arctic Cordillera (within the Northwest Territories). The area of individual ecozones within provinces and territories is given in Table 2.2.

CRITERIA FOR AQUATIC ECOSYSTEMS CLASSIFICATION

In general, classification of aquatic ecosystems is not as well developed as that for terrestrial ecosystems. For inland waters, drainage basins provide natural units, and much of the data pertaining to contaminants are on this basis. Climate influences the productivity and character of aquatic systems, and various proposals have been advanced to classify inland waters in terms of north-south climatic zones. Marine ecosystems can be classified by the following characteristics: seabed physiography, water temperature, ocean currents, land/water interface, depth, and species composition. These factors are taken into account, to the extent possible, in the analysis of the data on aquatic ecosystems. However, we have retained a very broad classification of aquatic systems, distinguishing oceanic systems (the Pacific, Atlantic and northern marine systems) from freshwater systems (inland waters).

*The designation of these regions as 'ecozones' was adopted for its compatibility with other terms already in use by the Canada Committee on Ecological Land Classification.

Table 2.1
Characteristics of Terrestrial Ecozones of Canada

Ecozone	Physiography	Vegetation	Soils/Surface Materials	Climate	Present Use
1 Tundra Cordillera	Mountainous highlands	Alpine and arctic tundra	Cryosolic, brunisolic; colluvium, moraine, rock	Cold, semi-arid, subarctic	Trapping, hunting recreation, tourism, mining
2 Boreal Cordillera	Mountainous highlands; some hills and plains	Boreal; some alpine tundra and open woodland	Brunisolic; colluvium, moraine, rock	Moderately cold, moist montane	Hunting, trapping, forestry, recreation, mining
3 Pacific Maritime	Mountainous highlands; some coastal plains	Coastal, western and mountain hemlock	Podzolic; colluvium, moraine, rock	Very wet, mild, temperate maritime	Forestry, fishing, urbanization, agriculture
4 Montane Cordillera	Mountainous highlands and interior plains	Mixed vegetation; conifer stands to sage brush fields	Luvisolic, brunisolic; moraine, colluvium, rock	Moderately cold, moist montane to arid	Forestry, agriculture, tourism, recreation
5 Boreal Plain	Plains; some foothills	Conifer and broadleaf boreal stands	Luvisolic; moraine, lacustrine	Moderately cold, moist boreal	Forestry, agriculture, recreation, trapping
6 Taiga Plain[1]	Plains; some foothills	Open woodland; shrub lands and wetlands	Cryosolic, brunisolic; organic, moraine	Cold, semi-arid, subarctic to moist boreal	Hunting, trapping, recreation
7 Prairie	Plains; some foothills	Short and mixed grasslands; aspen parkland	Chernozemic; moraine, lacustrine	Cool, semi-arid	Agriculture, urbanization, recreation
8 Taiga Shield	Plains; some interior hills	Open woodlands, some arctic tundra and lichen heath	Cryosolic, brunisolic; moraine, rock	Moist, cold boreal to cold, semi-arid, subarctic	Hunting, trapping, recreation
9 Boreal Shield[2]	Plains; some interior hills	Conifer and broadleaf boreal stands	Brunisolic; moraine, rock, lacustrine	Cold, moist boreal	Forestry, mining, recreation, tourism
10 Hudson Bay Plain	Plains	Wetlands, arctic tundra and some conifer stands	Cryosolic; organic, marine	Cold, semi-arid subarctic to cold boreal	Hunting, trapping, recreation
11 Mixed-Wood Plain	Plains; some interior hills	Mixed broadleaf and conifer stands	Luvisolic; moraine, marine, rock	Cool to mild boreal	Agriculture, urbanization, recreation
12 Atlantic Maritime	Hills and coastal plains	Mixed broadleaf and conifer stands	Brunisolic, luvisolic; moraine, colluvium, marine	Cool, wet temperate maritime	Forestry, agriculture, fishing, tourism
13 Southern Arctic	Plains; some interior hills	Shrub/herb/heath arctic tundra	Cryosolic; moraine, rock, marine	Cold, dry arctic	Hunting, trapping recreation, mining
14 Northern Arctic	Plains and hills	Herb-lichen arctic tundra	Cryosolic; moraine, rock, marine	Very cold, dry arctic	Hunting, trapping, recreation, mining
15 Arctic Cordillera	Mountainous highlands	Non-vegetated, some shrub/herb arctic tundra	Cryosolic; ice, snow, colluvium	Extremely cold, dry arctic	Hunting

[1]The term 'taiga' here refers to a zone of forest-tundra transition encircling the Northern Hemisphere.
[2]Boreal refers to the coniferous forest regions that bridge much of the mid-latitudinal belt of Canada.
Source: E. Wiken, "Terrestrial Ecozones of Canada", Background Working Report (Ottawa: Environment Canada, Lands Directorate, 1984).

Table 2.2
Provincial/Territorial Contributions to Ecozone Area
(square kilometres)

Ecozone	British Columbia	Alberta	Saskat-chewan	Manitoba	Ontario	Quebec
1 Tundra Cordillera						
2 Boreal Cordillera	207 535					
3 Pacific Maritime	197 040					
4 Montane Cordillera	419 445	43 855				
5 Boreal Plain	93 895	375 850	258 765	129 685		
6 Taiga Plain	29 885	68 090				
7 Prairie		166 975	253 645	70 515		
8 Taiga Shield		6 420	39 890	122 630		490 095
9 Boreal Shield[1]			100 030	248 455	652 180	693 705
10 Hudson Bay Plain				78 665	278 380	8 625
11 Mixed-Wood Plain[2]					138 020	56 935
12 Atlantic Maritime[3]						54 710
13 Southern Arctic						157 360
14 Northern Arctic						79 250
15 Arctic Cordillera						
Total	947 800	661 190	652 330	649 950	1 068 580	1 540 680

Ecozone	New Brunswick	Nova Scotia	Prince Edward Island	Newfound-land	Yukon	Northwest Territories	Total
1 Tundra Cordillera					227 745	149 215	376 960
2 Boreal Cordillera					218 235		425 770
3 Pacific Maritime							197 040
4 Montane Cordillera							463 300
5 Boreal Plain					23 975	425	882 595
6 Taiga Plain					5 495	453 780	557 240
7 Prairie							491 135
8 Taiga Shield				226 515		415 740	1 301 290
9 Boreal Shield[1]	490			122 985			1 817 845
10 Hudson Bay Plain						5 150	370 820
11 Mixed-Wood Plain[2]							194 955
12 Atlantic Maritime[3]	72 950	55 490	5 660				188 810
13 Southern Arctic				56 220	8 010	771 005	992 595
14 Northern Arctic						1 329 340	1 408 590
15 Arctic Cordillera						301 665	301 665
Total	73 440	55 490	5 660	405 720	483 450	3 426 320	9 970 610

[1]The figure for the Boreal Shield includes portions of the Great Lakes. If the Great Lakes are not included, the total for the Boreal Shield would be 1 780 095 km^2. The figure for the Ontario part of the Boreal Shield would be 614 430 km^2, without the Great Lakes.

[2]The figure for the Mixed-Wood Plain includes a portion of the Great Lakes. If the Great Lakes are not included, the total for the Mixed-Wood Plain would be 144 440 km^2. The total for the Ontario part of the Mixed-Wood Plain would be 87 505 km^2 if the Great Lakes are not included.

[3]The figure for the Atlantic Maritime ecozone includes the St. Lawrence River estuary. If the St. Lawrence River estuary is not included, the total for the Atlantic Maritime would be 154 480 km^2. The total for the Quebec part of the Atlantic Maritime would be 20 380 km^2 if the St. Lawrence estuary is not included. The St. Lawrence River estuary is defined as the portion of the river between Île d'Orléans and Anticosti Island.

SOCIO-ECONOMIC CHARACTERISTICS OF ECOZONES

The foregoing description of the ecological regions of Canada tells only part of the story. The broad characteristics (physiography, vegetation, soils and climate) are relatively stable over time under natural conditions, but human activities have the potential to alter these systems rapidly. A more complete picture, therefore, requires additional information on the socio-economic conditions and trends in each ecozone.

For this purpose, quantitative data relating to five broad categories of socio-economic activity have been examined. The results in each of the categories set out below are summarized by ecozone in Tables 2.3 and 2.4.

Population: The 1981 population and share of the national total; the percentage classified as 'urban'; and the age dependency ratio (the sum of the population under 15 or over 65, divided by the population between 15 and 65).

Labour Force and Employment Ratios: The 1981 experienced labour force and share of the national total; employment in the resource-based industries as a percentage of all industries in the ecozone, and employment in resource-based industries as a percentage of employment in goods-producing industries in the ecozone.

Land Use: Total area and percentage of the national total; percentage of the area that is productive forestland; percentage of the area used as farmland; and portion of the area used as provincially or federally designated parks. (Most recent figures available.)

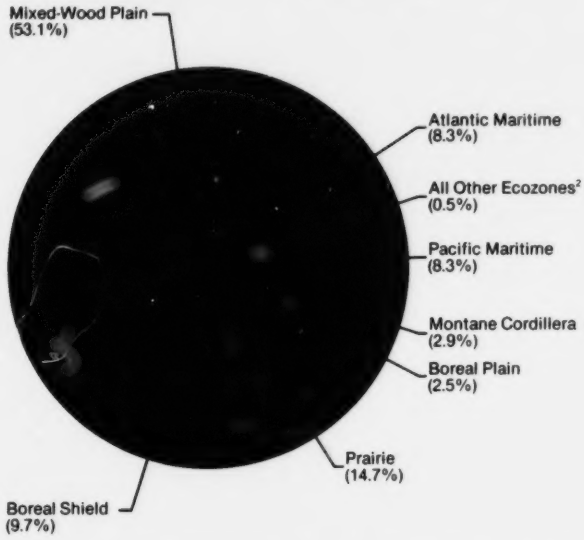
Market Values: Value of agricultural production and percentage of the national total; agricultural input/output ratio, i.e., cost of fertilizers, chemicals and farm fuel as a percentage of output (i.e., total value of agricultural production); and manufacturing value-added and share of the national total.

Energy Consumption: Energy consumption and percentage of the national total and the distribution of energy consumption by resource industries (mining, forestry, agriculture); manufacturing; transportation; and other (construction, residential, public administration and commerce). (Based on 1982 fuel and electricity consumption.)

Arrows are used to describe the direction and magnitude of change in each category, comparing 1971 with 1981 data, except for manufacturing value-added, where comparisons are for the years 1973 and 1981, and energy data, which compare 1978 consumption with 1982. The relative changes are indicated by the position of the arrows (i.e., unchanged, high positive, high negative, medium positive, and medium negative).

It is clear from Tables 2.3 and 2.4 that socio-economic characteristics vary greatly from one ecozone to another, both in magnitude and in rates of change. The high concentration of socio-economic activity in a limited area is strikingly apparent when we consider that 84 per cent of the population lives in four ecozones — the Mixed-Wood Plain (ecozone 11), the Atlantic Maritime (12), the Pacific Maritime (3), and the Prairie ecozone (7). These areas comprise slightly less than 11 per cent of the country's land mass. The Mixed-Wood Plain, which has 53 per cent of Canada's people and 2 per cent of its land, produces 70 per cent of manufacturing value-added and 40 per cent of agricultural value-added. The Mixed-Wood Plain, the Prairie ecozone and the Boreal Plain (including the Peace River region) account for 90 per cent of Canada's agricultural production. Other economic activities are similarly concentrated: metal mining in the Boreal Shield, oil production in the Prairie ecozone, and forestry in the Boreal Shield, Pacific Maritime and Atlantic Maritime zones. Table 2.4 shows the dominance of resource-based activity (as measured by energy consumption*) in lightly populated areas. Figure 2.1 illustrates the extreme unevenness of population distribution in Canada.

Figure 2.1
Population Distribution by Ecozone, 1981[1]



[1] Population of Canada was 24.3 million in 1981.
[2] Includes Boreal Cordillera, Tundra Cordillera, Taiga Plain, Taiga Shield, Hudson Bay Plain, Southern Arctic, Northern Arctic and Arctic Cordillera.
Source: Statistics Canada, 1981 Census.

*Energy consumption in northern ecozones is probably under-estimated, because the data are based on purchased fuel and electricity. Many resource industries in remote areas produce a good deal of the energy they consume, through hydro-electric power, wood burning, coal, etc.

How to Read these Tables

To illustrate how Tables 2.3 and 2.4 might be read, the data for Ecozone 3 (Pacific Maritime), which includes Vancouver and Victoria, show the following:

- The 1981 population, accounting for 8.3 per cent of the Canadian population, had changed by more than 20 per cent since 1971. More than 85 per cent of the population was urban, and this had changed by between 2 and 5 per cent since 1971. For every person in the under-15 or over-65 age group in 1981, there were two in the 15 to 65 age group; this ratio had decreased by between 5 and 15 per cent since 1971.
- The experienced labour force in 1981 accounted for 8.7 per cent of the national figure; the number had increased by more than 40 per cent since 1971. Those employed in resource-based industries accounted for 10 per cent of the experienced labour force and nearly 37 per cent of the all goods-producing industries; these percentages had changed by less than 5 per cent since 1971.
- This ecozone has only 2 per cent of the country's area. Almost 25 per cent of this area is covered with stocked, productive, non-reserved forest. Only 0.9 per cent was farmland and 15 per cent was designated parkland in 1981, and both these figures had changed by less than 5 per cent since 1971.
- In terms of the total value of agricultural production in 1981, this ecozone accounted for just over 3 per cent of the total for Canada, but the value (in constant 1971 dollars) had increased by between 31 and 50 per cent compared with 1971. In 1981, the costs for fertilizers, chemicals and farm fuel accounted for about 6 per cent of the total value of agricultural production in the ecozone, and this percentage had changed by less than 2 per cent since 1971. The figures for manufacturing value-added, in 1981, accounted for about 6.6 per cent of the overall figure for Canada, and this had changed by less than 10 per cent since 1973.
- Total energy consumed was 436.6 petajoules (10^{15} joules) in 1982, and this had increased by between 6 and 20 per cent since 1978. Transportation and 'other' each accounted for about 37 per cent of energy consumption in 1982, but the change since 1978 was between 6 and 20 per cent for transportation and more than 20 per cent for 'other'. Manufacturing accounted for about 24 per cent of energy consumption in 1982, and this changed by less than 5 per cent compared with 1978.

Table 2.3
Socio-economic Characteristics by Ecozone

Ecozone	Population			Labour Force & Employment Ratios		
	1981 Pop. 000s (% of national)	1981 % Urban	1981 Age Dependency Ratio	1981 Experienced Labour Force 000s (% of national)	1981 RB/All %	1981 RB/AGP %
1 Tundra Cordillera	1.2 ↘ (<0.01)	0	42.1 ↘	0.5 ↘ (<0.01)	64.0 ↘	95.5 →
2 Boreal Cordillera	25.8 ↑ (0.11)	57.3 ↓	43.2 ↓	14.25 ↑ (0.1)	16.0 ↘	62.9 ↘
3 Pacific Maritime	2 014 ↑ (8.3)	85.4 ↗	46.6 ↘	1 043 ↑ (8.7)	10.0 →	36.8 →
4 Montane Cordillera	698 ↑ (2.9)	58.4 →	50.7 ↘	335.7 ↑ (2.8)	22.6 →	59.4 ↘
5 Boreal Plain	612 ↗ (2.5)	41.4 ↑	58.9 ↓	277.0 ↑ (2.3)	29.7 ↘	68.9 ↘
6 Taiga Plain	15.4 ↗ (0.06)	45.5 →	60.6 ↓	6.255 ↑ (0.05)	18.7 ↘	67.5 ↘
7 Prairie	3 578 ↗ (14.7)	76.8 ↗	48.9 ↘	1 873 ↑ (15.6)	13.1 ↘	41.4 ↘
8 Taiga Shield	55.3 ↑ (0.23)	69.1 ↓	54.8 ↓	24.44 ↑ (0.2)	33.1 →	85.6 →
9 Boreal Shield	2 352 ↗ (9.7)	59.7 ↘	51.3 ↓	1 000 ↑ (8.3)	20.6 →	58.2 →
10 Hudson Bay Plain	10.0 ↘ (0.04)	12.3 ↓	81.4 →	2.850 → (0.02)	5.3 →	48.1 ↗
11 Mixed-Wood Plain	12 938 ↗ (53.1)	83.6 →	45.1 ↘	6 545 ↗ (54.5)	4.6 →	13.8 →
12 Atlantic Maritime	2 019 ↗ (8.3)	50.4 ↘	52.7 ↘	875.0 ↗ (7.3)	15.4 →	49.5 →
13 Southern Arctic	14.4 ↑ (0.06)	21.9 ↘	69.7 ↓	4.910 ↑ (0.04)	11.8 →	64.2 ↗
14 Northern Arctic	10.0 ↑ (0.04)	23.0 ↘	78.0 ↓	3.300 ↑ (0.03)	8.3 →	54.3 ↗
15 Arctic Cordillera	0.9 ↑ (<0.01)	0	88.8 ↘	0.225 ↑ (<0.01)	2.3 ↘	50.0 ↓

Population
The population figures are based on the 1981 census, and the arrow indicators refer to the change between 1971 and 1981. For the total population change, the ranges indicated by the pointer are as follows:

0 to ± 5.0% → ± 5.1% to ± 20.0% ↗ ≥ ± 20.1% ↑↓

For the percentage of the population that is urban, the ranges indicated by the pointer are:

0 to ± 2.0% → ± 2.1% to ± 5.0% ↗ ≥ ± 5.1% ↑↓

For the age dependency ratio $\left(\frac{<15 + >65}{15 \text{ to } 65} \times 100\right)$ the ranges are:

0 to ± 5.0% → ± 5.1% to ± 15.0% ↗ ≥ ± 15.1% ↑↓

Labour Force & Employment Ratios
The *experienced labour force* is derived by deleting from the total labour force unemployed persons 15 years of age and over who have never worked or who had worked only after January 1, 1970 or January 1, 1980, as applicable.

Resource-based Industries (RB) include agriculture; forestry; fishing and trapping; mines, quarries and oil wells; fish product industries; fruit and vegetable processing industries; sawmills, planing mills and shingle mills; pulp and paper mills; and smelting and refining.

All Goods-producing Industries (AGP) include primary and secondary industries and exclude the service sector (transportation; communication and other utilities; trade; finance, insurance and real estate; community, business and personal services; public administration; and defence).

For the experienced labour force, the figures are 1981 data and the arrow indicators refer to the change between 1971 and 1981.

For the total experienced labour force change, the ranges are:

0 to ± 15.0% → ± 15.1% to ± 40.0% ↗ ≥ ± 40.1% ↑↓

For the $\frac{RB}{All}$ and $\frac{RB}{AGP}$ percentages, the ranges are as follows:

0 to ± 5.0% → ± 5.1% to ± 20.0% ↗ ≥ ± 20.1% ↑↓

Table 2.3, continued
Socio-economic Characteristics by Ecozone

Ecozone	Land Use				Market Values		
	Land Area 000 km² (% of national)	% Stocked, Productive, Non-reserved Forestland	1981 % Farm Land	1981 % Designated as Parks	1981 Total Value of Agricultural Production $ millions (% of national)	1981 Agricultural Input/Output %	1981 Manufacturing Value-added $ millions (% of national)
1 Tundra Cordillera	377 (3.8)	7.3		1.3 ↑			
2 Boreal Cordillera	426 (4.3)	18.5		8.6 ↑			*
3 Pacific Maritime	197 (2.0)	24.7	0.86 →	15.2 →	185.7 ↗ (3.1)	6.4 →	2 025 → (6.6)
4 Montane Cordillera	463 (4.6)	55.6	3.0 ↓	4.6 ↗	98.4 ↗ (1.6)	10.9 →	718.7 → (2.3)
5 Boreal Plain	883 (8.9)	29.4	12.0 →	1.5 →	463.2 ↑ (7.7)	20.3 ↑	275.4 ↑ (0.9)
6 Taiga Plain	557 (5.6)	19.0		8.0 →			*
7 Prairie	491 (4.9)	0.9	86.8 →	0.3 ↑	2 504 ↑ (41.7)	14.8 ↑	2 570 ↑ (8.4)
8 Taiga Shield	1 301 (13.0)	6.0					1.630 ↗ (<0.01)
9 Boreal Shield	1 818 (18.2)	49.5	0.88 ↘	6.8 ↗	130.0 → (2.2)	10.0 →	2 089 ↑ (6.8)
10 Hudson Bay Plain	371 (3.7)	1.7		6.5 →			*
11 Mixed-Wood Plain	195 (2.0)	14.2	40.5 ↘	0.6 ↑	2 383 ↗ (39.7)	10.5 →	21 724 ↗ (70.9)
12 Atlantic Maritime	189 (1.9)	53.8	8.5 ↓	1.3 →	234.5 → (3.9)	13.0 →	1 268 ↗ (4.1)
13 Southern Arctic	993 (10.0)	0.3					*
14 Northern Arctic	1 409 (14.1)						*
15 Arctic Cordillera	302 (3.0)			7.1 ↑			

Land Use
The land area figures include the following areas:
38 × 10^3 km² Great Lakes in Ecozone 9
51 × 10^3 km² Great Lakes in Ecozone 11
34 × 10^3 km² St. Lawrence River estuary in Ecozone 12

Data for stocked, productive, non-reserved forestland are not dated. Although they were compiled in 1981, they are based on provincial inventories that were assembled at different times.

Farmland area (1981) includes cropland, improved pasture, summer fallow, woodland and other unimproved farmland. Designated parks (1981) include wilderness areas >162 km², unique natural areas and natural environment recreation areas >2.02 km² as designated by federal and provincial governments.

The percentage changes in the amount of farmland areas and designated parks are comparisons of the differences between 1971 and 1981, with ranges as follows:

0 to ±5.0% → ± 5.1% to ± 10.0% ↗ ≥ ± 10.1% ↑↓

Market Value
All figures are in constant 1971 dollars. Data are 1981 figures.

The percentage change in the value of agricultural production is a comparison of the differences between 1971 and 1981, with the following ranges:

0 to 30% → 31% to 50% ↗ ≥ ±51% ↑↓

Agricultural input/output depicts the costs for fertilizers, chemicals and farm fuel as a percentage of the total value of agricultural production.

The percentage change in input/output ratios is for differences between 1971 and 1981, with ranges as follows:

0 to 2.0% → 2.1% to 5.0% ↗ ≥ ±5.1% ↑↓

Manufacturing value-added figures are for 1981. An asterisk (*) indicates that data are confidential either because there were fewer than three establishments or because one or two establishments dominated the value-added figure.

The ranges indicated by the pointer, for the differences between 1973 and 1981, are:

0 to 10.0% → 10.1% to 25.0% ↗ ≥25.1% ↑↓

Table 2.4
Energy Consumption by Ecozone, 1982

Ecozone	Energy Consumption (10^{15} Joules)	% Consumption by Sector			
		Resource-based Activities	Manufacturing	Transportation	Other
1 Tundra Cordillera	0.926 ↑	71 ↑		10 ↓	19 ↑
2 Boreal Cordillera	11.79 ↑	39 ↑	0.2 →	21 ↑	40 ↑
3 Pacific Maritime	436.6 ↗	2 →	24 →	37 ↗	37 ↑
4 Montane Cordillera	229.3 ↗	25 ↑	26 →	22 ↗	28 ↑
5 Boreal Plain	237.8 ↗	26 ↑	12 →	24 ↗	38 ↑
6 Taiga Plain	6.604 ↑	34 ↑	6 →	17 ↓	43 ↑
7 Prairie	1 053 ↗	11 ↑	16 →	29 ↗	45 ↗
8 Taiga Shield	29.20 ↘	63 ↘	0.1 ↘	16 ↘	21 ↗
9 Boreal Shield	649.2 →	10 ↘	34 ↘	22 ↑	33 →
10 Hudson Bay Plain	2.662 ↘	3 ↘	0.2 ↘	41 ↓	56 →
11 Mixed-Wood Plain	2 611 ↘	2 →	29 ↘	28 ↘	41 →
12 Atlantic Maritime	399.6 ↘	5 ↗	27 ↘	30 ↘	38 →
13 Southern Arctic	3.316 →	0.1 ↓		30 ↓	70 ↑
14 Northern Arctic	2.978 ↑	19 ↑		23 ↓	58 ↑
15 Arctic Cordillera	0.195 ↗			37 ↓	63 ↑

Energy Consumption
Provincial energy use statistics were converted to ecozone-based data by applying a variety of weighting factors or allocators, including population; consumption of purchased fuel and electricity for mining and manufacturing; area of stocked, productive, non-reserved forestland; kilometres of oil and natural gas pipeline; fuel expenditures for agriculture; and degree-day times transfer co-efficients for residential energy consumption. The figures are 1982 data.

The sub-grouping of the energy consumption data has been compiled in terms of four broad categories:

Resource-based Activities: mining, agriculture and forestry

All Manufacturing

Transportation: rail, marine, pipeline, road and urban transport and retail pump sales

Other: construction, residential, public administration and commercial.

The ranges indicated by the pointer, for the differences between 1978 and 1982, are:

0 to ± 5% →
± 6% to ± 20% ↗↘
≥ ± 21% ↑↓

3

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INTRODUCTION

Canada's agriculture is vital to the country's social, cultural and economic future. A recent Senate committee report on soil degradation states that less than 9 per cent of Canada's land area is capable of being cultivated and, of that, only about half is actually cropped. About one job in 10 in Canada depends on agriculture or agriculture-related industries. Approximately 40 per cent of the nation's gross national product is generated by agribusiness,* and agriculture contributes about 10 per cent to export earnings.[11]

Concern is growing about the implications of high-yield agricultural production, particularly when coupled with such soil-degrading factors as wind and water erosion, organic matter loss, salinization, acidification, contamination, compaction and disturbance of agricultural soils. These concerns are linked to technological and market influences that have resulted in changes in cropping practices, conversion of prime agricultural lands to other uses, and economic pressures that encourage farmers to seek short-term solutions. Their combined effect led the Senate committee to conclude that Canada is facing the most serious agricultural crisis in its history.

The ecozones that are considered agriculturally important are the Pacific Maritime, Montane Cordillera, Boreal Plain, Prairie, Boreal Shield, Mixed-Wood Plain and Atlantic Maritime. However, three ecozones (Boreal Plain, Prairie and Mixed-Wood Plain) account for over 90 per cent of agricultural activity, in terms of both production and area. To the extent possible, data have been compiled by ecozone. Neverthless, some data were available only on a provincial or regional basis.

RECENT CHANGES IN THE PATTERN OF AGRICULTURAL ACTIVITY

Agricultural practices vary widely across Canada. In some areas fruit and vegetables predominate, in others wide-row crops like corn and soybeans are paramount, and in others close-row crops like wheat and oats are more common. The size of farms, the use of inputs (fertilizers and pesticides) and technological sophistication also vary from region to region. Data related to such characteristics are collected by Statistics Canada on a comprehensive basis, as part of the five-year census surveys.

This database was used to generate Table 3.1 which summarizes a number of the conventional agricultural statistics by ecozone. The data for 1981 are given along with the percentage change since 1971.

At the national level, the figures confirm that both the number of farms and farmland area have been decreasing and that the average farm size has been increasing. The exception to this general statement is in the Montane Cordillera, where the combination of an increasing number of farms and decreasing farmland area has resulted in a major decrease in the average farm size. Despite the decrease in total farmland area, there have been increases in cropland area in all regions. The amount of improved pasture has also increased substantially in some regions (Montane Cordillera, Boreal Plain and Prairie), but it has decreased in all other regions.

Agriculture-related environmental changes vary with cropping practices. Wide-row crops, such as corn and soybeans, are generally associated with high rates of use of fertilizers and pesticides, and with increased risks of soil erosion. Close-row crops, such as wheat and oats, are frequently associated with decreased soil organic matter and nutrient content and (especially when irrigated) with the spread of salinization. Forage crops, such as hay and alfalfa, tend to retain the natural characteristics of the land, although they are sometimes associated with feed lots and intensive livestock operations where runoff may pollute local water bodies. Summer fallowing has been practised to conserve soil moisture and nutrient supplies, but when (as in the Prairie region) it involves unplanted land, it may contribute to wind and water erosion and to salinization. The extent of these cropping practices and the percentage change between 1971 and 1981 are shown in Table 3.2.

Overall, wide-row cropping is the only practice that has increased significantly since 1971, and summer fallowing has decreased. Wide-row crops are grown primarily in the Mixed-Wood Plain, especially in southwestern Ontario, close-row crops in the Prairie ecozone, and forage crops in the Prairie and Mixed-Wood Plain.

On a regional basis, the Atlantic Maritime has recorded decreases in crop areas and an increase in summer fallow. In the Mixed-Wood Plain there have been significant decreases in summer fallow, forage and close-row crops coupled with a major increase in wide-row crops. In the Prairie region, where summer fallowing is common, there has been a decrease in this category of just under 10 per cent; other categories have all increased. Areas assigned to all cropping practices and summer fallow have increased in the Boreal Plain and Pacific Maritime ecozones.

FACTORS AFFECTING THE STATE OF AGRO-ECOSYSTEMS

Many factors either reflect or affect the state of agro-ecosystems. Climate, soil conditions, cropping practices and proximity to other activities (e.g., urban set-

*The term agribusiness is employed in the broad sense to include all businesses that support agriculture (i.e., agricultural chemicals, machinery, extension services and research and development), the food processing and distribution industry and, of course, farming itself. The latter, however, contributes only 4 per cent to GNP (based on value-added) and 5 per cent to employment. From an environmental perspective, production in agriculture is only partially accounted for in GNP; left out are the natural inputs of solar energy, nutrients and vital climate conditions. In other words, the concept of production in the National Accounts is limited to the measurement of 'economic' factors, i.e., labour, capital, purchased materials.

Table 3.1
Summary of Agriculture by Ecozone, 1981 and % Change, 1971-1981
(thousands of hectares)

		Pacific Maritime		Montane Cordillera		Boreal Plain		Prairie		Boreal Shield		Mixed-Wood Plain		Atlantic Maritime		Canada[2]	
Total Area		19 704		46 330		88 259		49 114		181 784		19 496		18 881		997 061	
	Units	1981	% Change 71-81	1981	% Change 71-81	1981	% Change 71-81	1981	% Change 71-81	1981	% Change 71-81	1981	% Change 71-81	1981	% Change 71-81	1981	% Change 71-81
Number of farms	no.	8 436	+1	9 866	+17	40 140	−9	116 009	−12	13 695	−21	113 373	−15	16 771	−28	318 361	−13
Farmland Area[1]	000s ha	170	+2	1 385	−15	10 585	−1	42 626	−3	1 597	−10	7 888	−8	1 609	−18	65 889	−4
Average Farm Size	ha	20	+2	140	−28	264	+8	367	+11	117	+14	70	+8	96	+18	207	+10
Cropland Area	000s ha	75	+32	246	+31	4 886	+18	19 934	+10	515	+7	4 722	+10	583	+4	30 966	+11
Improved Pasture Area	000s ha	30	−16	192	+61	824	+42	2 124	+31	197	−18	861	−35	175	−19	4 405	+6

[1]Includes woodlots, summer fallow, native pasture, range lands, sloughs, etc. These lands account for 30.5 million hectares for the whole of Canada.
[2]Data from the Yukon and Northwest Territories are included.
Data for Canada include small contributions from other ecological regions.
Minor changes in definition of census farms may slightly affect data comparability.
Source: Statistics Canada, Census of Agriculture, 1981.

Table 3.2
Summary of Agricultural Cropping Practice by Ecozone, 1981 and % Change, 1971-1981
(hundreds of hectares)

	Pacific Maritime		Montane Cordillera		Boreal Plain		Prairie		Boreal Shield		Mixed-Wood Plain		Atlantic Maritime		Canada	
Cropping Practice	1981	% Change 71-81	1981	% Change 71-81	1981	% Change 71-81	1981	% Change 71-81	1981	% Change 71-81	1981	% Change 71-81	1981	% Change 71-81	1981	% Change 71-81
Wide-row Crops	177	+46	56	+11	228	+328	3 542	+80	192	+53	18 978	+57	762	+18	23 935	+59
Close-row Crops	72	+12	401	+23	36 687	+19	177 905	+9	1 278	+1	11 500	−7	1 713	−3	229 556	+9
Forage Crops	735	+5	2 874	+56	14 783	+25	26 600	+18	4 916	−8	17 910	−26	4 400	−10	72 258	+1
Summer Fallow	33	+120	111	+62	10 956	−23	84 575	−9	225	+51	914	−19	197	+48	97 019	−10

Wide-row crops include corn, soybeans, sunflowers, dry field peas, field beans, potatoes, vegetables.
Close-row crops include oats, barley, mixed grain, all wheat, flaxseed, canola, mustardseed, rye.
Forage crops include alfalfa, tame hay and other fodder crops.
Totals do not add to actual Canada totals in all cases because certain crops were not assessed and the Yukon and Northwest Territories were not included in the database.
Source: Statistics Canada, Census of Agriculture, 1981.

Table 3.3
Factors Reflecting or Having Major Influence on the State of Agro-Ecosystems

Factors	Pacific Maritime	Montane Cordillera	Boreal Plain	Prairie	Boreal Shield	Mixed-Wood Plain	Atlantic Maritime
Soil Quality							
organic matter loss	■	■	■	■		□	□
nutrient content			■	■		□	□
acidification	■	■	■	■		□	
salinization				■			
erosion (wind/water)	■	■	■	■	□	■	■
compaction	■	■		□			
Land Use Change							
agriculture to urban	■	□	□	□		■	□
wetlands to agriculture			■	■		■	□
development activities	□	□		□			
Cultural Practices							
crops/livestock	□		□	■		■	□
monoculture			□	■		■	
fertilizers	■	■	■	■		■	■
pesticides	■	■	■	■	□	■	□
genetic diversity	□		□	■		□	□
External Factors							
climate/climate change	□	□	□	□	□	□	□
air pollutants	□					□	□
Economic Factors							
land/production values	■	■	□	■	□	■	□
input costs (fertilizers, chemicals, fuel)	■	■	□	■	□	■	□

■ Primary importance
□ Secondary importance

Table 3.4
Proportion of Nutrient Content of Harvested Crop to Nutrient Content of Fertilizer Applied, 1960-1980

	Total content of N + P + K in the harvested crop as a ratio of the N + P + K content of the fertilizer applied[1]						
Province or Region	**1960-62**	**1963-65**	**1966-68**	**1969-1971**	**1972-74**	**1975-77**	**1978-1980**
British Columbia	0.96	0.79	0.73	0.66	0.54	0.46	0.43
Alberta	7.42	4.61	2.84	3.25	2.02	1.54	1.27
Saskatchewan	26.70	14.26	6.23	17.18	7.04	5.66	2.77
Manitoba	12.50	7.45	2.59	2.96	1.68	1.29	0.86
Ontario	1.12	0.82	0.62	0.56	0.48	0.51	0.51
Quebec	0.96	0.71	0.50	0.38	0.26	0.25	0.28
Atlantic Provinces	0.51	0.47	0.42	0.38	0.37	0.39	0.40
Canada	3.55	3.00	1.96	2.08	1.48	1.35	1.04

[1] A figure of 1.00 would imply a balance between applied fertilizer input and nutrient uptake. (A figure of less than 1.00 would imply a greater application of fertilizer than the calculated nutrient content of crops. Greater than 1.00 would imply that the crops are dependent for nutrients on natural fertility of the soils.) See text for further details.

Source: R.T. Coupland, "Nutrient balance in the croplands of the world", Report prepared at the request of Environment Canada, March 1982.

tlements and industrial developments) also vary considerably within and between ecozones. The degree of influence of these factors changes constantly, and the evaluation of their relative importance will vary from study to study and from time to time.

A broad summary of these various factors, shown in Table 3.3, reflects the subjective views of a number of agricultural experts. Although this informal judgement is perhaps too simplistic, it nevertheless conveys a general picture of the situation across Canada. This report deals with many, but not all, of the factors identified in the table.

SOIL QUALITY

In the final analysis, maintenance of soil quality determines whether agricultural production can be sustained over time. Factors that, individually or in combination with others, serve as indicators of changing soil quality and agriculture sustainability include organic matter loss, nutrient content, acidification, salinization, erosion and compaction.

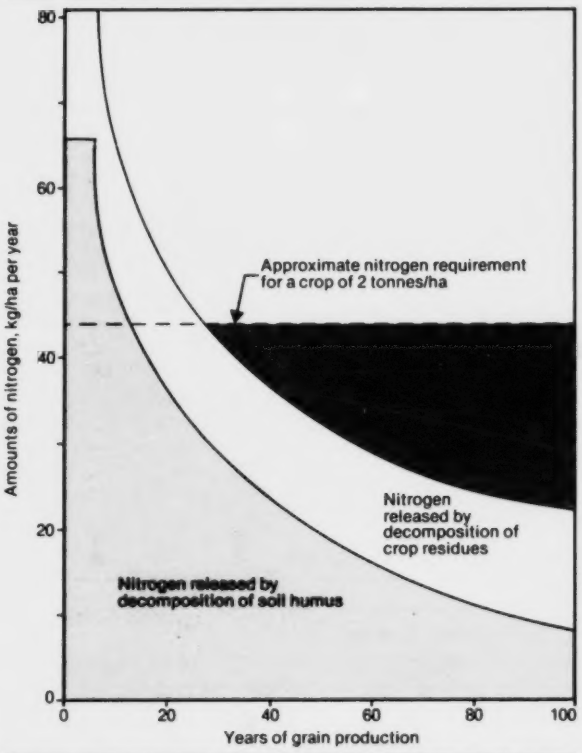
Organic Matter Loss

When native soils are cultivated, the quantity of plant residues returned to the soil is reduced. Sometimes almost everything is removed, as was the case when crops were bound and hauled away to be threshed, or when straw and stubble were burned off. In addition, soil that has been cultivated but not planted has a higher moisture content, which accelerates greatly the decomposition of the original organic matter. As the organic matter content of soils declines, the capacity of the native soil humus to continue to provide nitrogen for crops decreases. Loss of organic matter also decreases the soil's water-holding capacity and increases its susceptibility to compaction and to erosion by water or wind.

It has been estimated that the soil organic matter content of cultivated prairie soils has declined by as much as 37 to 48 per cent compared with native soils.[2] There have been similar reductions in nitrogen content and smaller but distinct decreases in phosphate levels. In Ontario and Quebec there may have been as much as a 50-per cent decline in organic matter content since cultivation began, and in the Atlantic provinces, where the organic matter content was low to begin with, there has been a serious deterioration of soil structure.

Figure 3.1 illustrates the relationships in the supply of available nitrogen that occur over time under a cropping system of continuous grain production in the prairie region. If yield is to be constant after some years of grain production, there is a gradually increasing need for fertilizer nitrogen to supplement the decreasing amount of available nitrogen from the soil humus. The actual reduction in available nitrogen from soil humus and the amount of nitrogen required in the form of fertilizer depend on other factors, such as the type of soil, cropping practices (e.g., rotation) and climate.

Figure 3.1
Compensation of Nitrogen Fertilizer Required to Maintain Continuous Grain Production of 2 Tonnes per Hectare
(based on virgin soils of the prairies)

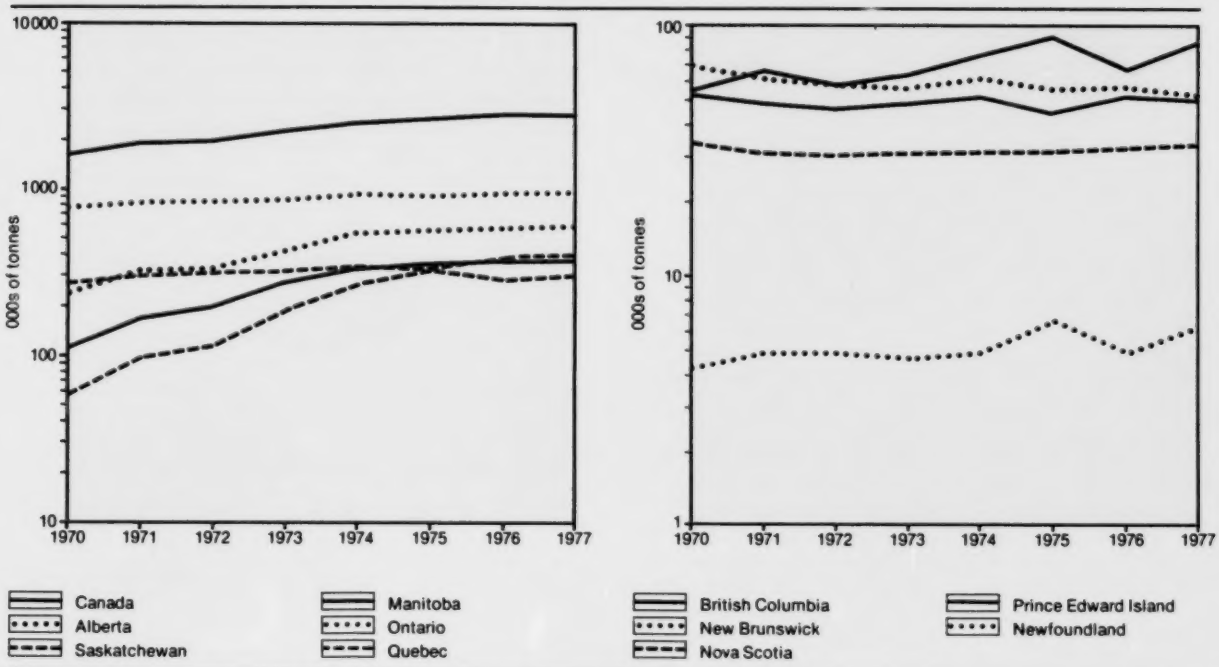


Source: C.F. Bentley, 1984. Adapted from University of Alberta *Agriculture & Forestry Bulletin* 5/4 (1982).

Nutrient Content

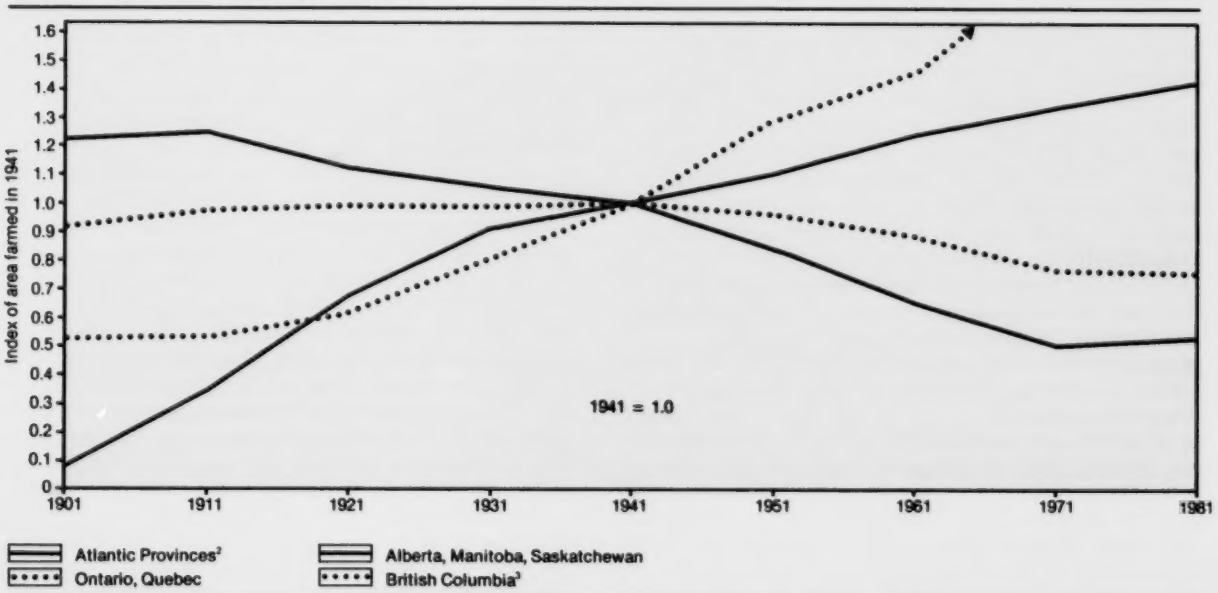
Nitrogen, phosphate (P_2O_5) and potassium are among the essential plant nutrients. As crops are harvested and removed, there is a change in the overall supply of these nutrients in soils. The conventional way to restore this balance is through the application of fertilizers, either by manuring or through the use of chemical fertilizers. This has been the practice to varying degrees in different parts of the country for many years. Ontario accounts for the greatest purchase of fertilizers, and southwestern Ontario has the highest rate of application per hectare in the country. The province with the greatest rate of increase was Saskatchewan, followed by Manitoba and Alberta. For Canada as a whole, there was a steady increase in fertilizer

Figure 3.2
Fertilizer Sales, by Province and Canada, 1970-77



Source: Statistics Canada, *Fertilizer Trade*, Annual Catalogue 46-207.

Figure 3.3
Index of Improved Farmland, 1901-1981[1]



[1] All index values are calculated as proportions of the 1941 area for each region.
[2] Atlantic provinces include Newfoundland after 1971.
[3] Rise in British Columbia index is attributed to the introduction of agriculture to the Peace River area. (B.C. index for 1971 and 1981 was 1.97 and 2.62 respectively.)
Source: Statistics Canada, Census of Agriculture, various years.

use of about 9 per cent annually during the 1970-77 period (see Figure 3.2).

An analysis of the input-output balance for these major nutrients requires consideration of much more than just the nutrient input in the form of fertilizers and the nutrient loss in the harvested crop. For example, the fixation of atmospheric nitrogen through the increasing use of leguminous crops, the loss of fertilizer nitrogen through leaching and/or runoff, the return of nutrients in the form of crop residues, and the transfer of nutrients from hayland and livestock feed to cropland by manuring all contribute to the total nutrient balance for agricultural ecosystems.

Nevertheless, one analysis of the relationship between nutrient input (in the form of applied fertilizers) and output (in the form of the nutrient content of crops) provides an approximation of the dynamics of nutrient balance in Canadian soils (see Tables 3.4 to 3.6).[6] The approach used in this study was to calculate the nutrient and dry matter content of harvested crops on a crop-by-crop basis, and to compare these results with nutrient input calculated by converting data on fertilizer use to an elemental nutrient basis — nitrogen (N), phosphorus (P) and potassium (K). From time series data, it would seem that the situation changed considerably over the period between 1960 and 1980. In the prairie provinces, for example, in 1960-62, the nutrient uptake of the harvested crop was derived principally from the natural nutrient content of the soil. Twenty years later, the situation had changed considerably. The calculations show that although the nutrient content (as measured by N + P + K) of crops in Alberta and Saskatchewan still exceeds the amount applied in fertilizer, in all other regions the nutrient removed in the form of crops is less than that added through fertilizers.

Increased dependence on fertilizers in this region may be accounted for by changes in agricultural techniques rather than by a drastic decline in the natural fertility of soils. Nonetheless, the increasing use of fertilizer suggests a need to compensate for nutrient loss, as well as the stringent demand for nutrients associated with new high-yield cultivars.

Although these results are derived from calculations and do not take into account all nutrient inputs and outputs, they do serve to draw attention to the possibility that the basic stock of these nutrients in prairie soils is being depleted, and the likelihood that excessive amounts of these nutrients are being applied in the form of fertilizers in other regions of the country. Some of these nutrients could be leaching into groundwater systems or polluting streams through erosion or runoff.

These considerations should emphasize the need to consider nutrient balance and careful management of farmland, in harmony with ecological factors of soil revitalization and the effect of different cropping practices. These factors may grow in importance if farmers are under pressure to increase agricultural yield in the next decade or two.

Acidification

Soil acidity is determined, in part, by the nature and extent of the underlying geological formations, by climate and by the type of vegetative cover. Acidification in northern temperate climates is often a natural and continuing soil process, although it may be accelerated by two major forms of human intervention: the use of nitrogen fertilizers and the emission of sulphates and nitrates by industry and transportation.

Acidification is of concern because it alters the natural balance of macronutrients (N, P and K) and because it may increase the solubility of some trace elements (micronutrients) in the soil, leading to toxic concentrations in plants or streams through runoff. Crop growth is reduced in acidified soils, and applications of increasing amounts of lime may be required to maintain optimal soil conditions. Without liming, the cumulative effect of acidification may gradually reduce the yield of cereal crops like barley and legumes like alfalfa, possibly to uneconomic levels. In some areas (e.g., in significant parts of the Prairie ecozone) soils tend naturally to be alkaline, and increased acidification could be beneficial.

The natural process of acidification (the loss of basic cations) by leaching and crop removal proceeds at varying rates depending on the climate, crop and nature of the soil. One method used to estimate the rate of acidification is to express acidity in terms of the amount of lime (calcium carbonate, $CaCO_3$) per hectare needed to neutralize it. Acidification of surface soils can range from an annual rate of less than 50 kg/ha $CaCO_3$ equivalent (e.g., with continuous cereal crop, in a semi-arid area) to more than 500 kg/ha $CaCO_3$ equivalent with heavily fertilized row crops in a humid region.[5]

Estimates of the relative average annual contribution to soil acidity by atmospheric deposition and by fertilizer use are shown in Table 3.7. For the country as a whole, the contribution to soil acidity from long-range atmospheric deposition is less than one-quarter of that from fertilizers, but this proportion is much higher (from one-third to two-thirds) in eastern Canada.

Environmental conditions such as soil quality, climate and atmospheric depositions, and agricultural practices (fertilizer use, liming, cropping practices) vary greatly from region to region and from farm to farm. The problem must, therefore, be considered not only at the regional level but also by individual farmers. This must be emphasized, because both fertilizer use and deposition of long-range acidic precipitation can be expected to increase in the future.

Liming of soils is an easy solution to the problem of acidification. While liming is carried out in parts of Canada, there are some areas, such as the prairie provinces, where the practice has not been widely adopted. This may be due in part to the lack of local sources of lime, to questions of availability or cost, or merely to insufficient appreciation of the benefits.

Table 3.5
Area Harvested and Total Content of Dry Matter, N, P, and K in the Annual Canadian Harvest by Crop Category, 1978-1980

Crop Category	Area harvested (thousands of hectares)	Content of harvest (kilotonnes)			
		Dry Matter	Nitrogen (N)	Phosphorous (P)	Potassium (K)
Wheat	10 734	17 051	410	77	99
Barley	4 207	8 941	194	44	56
Maize	877	4 195	78	15	15
Canola and mustard	2 858	2 892	104	26	27
Oats	1 628	2 876	65	13	14
Mixed grains and buckwheat	652	1 510	30	6.0	6.9
Potatoes	110	602	9.3	1.4	12
Linseed	678	566	22	3.6	4.8
Soybeans	284	562	37	3.9	10
Rye	320	471	11	1.9	2.6
Sugar beets	43	268	2.9	0.7	3.5
Pulses	135	189	7.9	0.9	2.4
Sunflower seed	130	157	4.5	0.9	1.1
Fruits and berries	78	138	1.0	0.1	1.6
Vegetables	93	136	3.4	0.5	4 2
Tobacco	51	91	0.8	..	0.4
Other roots and tubers	3	24	0.3	..	0.4
Total	22 879	40 670	981	193	2 660

Source: R.T. Coupland, "Nutrient balance in the croplands of the world", Report prepared at the request of Environment Canada, March 1982.

Salinization

Soil salinization is a process involving the redistribution of the salts (usually sulphates, chlorides, carbonates and bicarbonates of calcium, magnesium and sodium) that are normal constituents of soil. It is a phenomenon that occurs naturally, but it is increased by agricultural practices. It is a problem of particular concern in the Prairie ecozone.

Surface evaporation of water containing the soluble salts causes an accumulation of such salts in the topsoil. The condition is measured by the conductivity of saturated water extracts of the surface water. When the conductivity exceeds 4 000 microSiemens per centimetre, a soil is considered to be saline. At this level of salinity many crops will still grow, but at 14 000 microSiemens per centimetre, only very tolerant native weeds can survive. High levels of salinity reduce germination and growth of most crops by interfering with water and nutrient transport mechanisms across the soil-root interface.

Two aspects of agricultural practice contribute to soil salinization. The first, and more extensive, is referred to as dryland salinization. This occurs following a shift from native vegetation to annual grain crops that use less water. More water percolates into the soil, raising the water table. The higher water table results in more areas where the water comes to the surface and evaporates, leaving the salts behind. The situation is exacerbated by summer fallow, when no crop is grown.

The second type of salinization occurs in areas under irrigation, where water tables are raised because of leakage from irrigation canals or excessive water applications.

The extent of this problem has been poorly quan-

Table 3.6
A Comparison of the Amount of Fertilizer N + P + K Applied and the Total Content of N + P + K in the Crop Harvested, 1978-1980

Province or Region	N + P + K Content		
	1 Fertilizer Applied (kg/ha)[1]	2 Crop Harvested (kg/ha)[2]	Harvested crop as a ratio of N + P + K content of fertilizer[3]
Atlantic Provinces	261	104	0.40
Quebec	273	76.5	0.28
Ontario	199	102	0.51
Manitoba	64.0	55.0	0.86
Saskatchewan	18.8	52.2	2.77
Alberta	51.5	65.5	1.27
British Columbia	150	64.4	0.43
Canada	59.0	61.5	1.04

[1]Estimated by dividing the amount of fertilizer N + P + K consumed by the calculated area harvested.

[2]Estimated by dividing the calculated content of N in the non-leguminous crops for which area data are available by the area of those crops, and adding the value obtained by dividing the calculated content of P + K in all crops for which area data are available by the area of those crops.

[3]Estimated by dividing column 2 by column 1.

Source: R.T. Coupland, "Nutrient balance in the croplands of the world", Report prepared at the request of Environment Canada, March 1982.

Table 3.7
Approximate Average Annual Contribution to Soil Acidity by Atomospheric Deposition and Fertilizer Use
($CaCO_3$ equivalent required for neutralization: kilograms of $CaCO_3$ per hectare per year)

Province or Region	Atmospheric Deposition (1977-79)[1]	Fertilizer Use (1974-79)[2]	Total
Atlantic Provinces	30	84	114
Quebec	35	51	86
Ontario	33	90	123
Manitoba	5	72	77
Saskatchewan	0	12	12
Alberta	2	51	53
British Columbia	5	66	71

[1]Based on estimated contribution of long-range transported acidity from precipitation. Local deposition from point sources such as smelters and gas plants is not reflected in these data.

[2]Based on fertilizer sales data assuming an average requirement of 3 g of $CaCO_3$ per gram of nitrogen and expressed in terms of unit area of improved land. In some fields, acidity generated by fertilizer application may exceed 500 kg/ha of $CaCO_3$ equivalent per year.

Source: D.R. Coote et al., *An Assessment of the Degradation of Agricultural Lands in Canada* (Agriculture Canada, L.R.R.I., Contribution No. 118, 1981).

tified to date. Such quantification is complicated by the fact that in any one year salinization may appear to increase at some sites and decrease or remain unchanged at others. These variations are influenced by local differences in climate, water table levels and cropping practices.

Some estimates suggest that the area exhibiting dryland salinity has increased two- to four-fold during the past 10 to 15 years in different parts of Saskatchewan and Alberta and could be expanding at a rate of 10 per cent per year.[5] In some areas, grain yields have been reduced by half in soils exhibiting salinization.

Dryland salinization tends to be spotty, involving areas of 1 to 10 hectares, but when added together, these total some 2.2 million hectares. Another 100 000 hectares in Alberta and Saskatchewan suffer salinization exacerbated by irrigation.

Rehabilitation of severely salinized soils is technically difficult, and most land so affected is lost to agriculture. (There has been some success in the Salinas Valley, where drainage ditches are used to lower the water table and consequently the salt level.)

Erosion and Compaction

Soil erosion, particularly erosion by water, occurs to a limited degree even on well-vegetated undisturbed land. When the soil is exposed without the protection of vegetation, erosion is accelerated. Silty soils low in organic matter tend to be those most easily eroded. Erosion removes organic matter and the very fine-grained mineral fractions that have the greatest capacity to retain and supply plant nutrients. The annual rate at which soil forms in Canada is estimated to be between 0.25 tonnes per hectare (t/ha) and just over 1 t/ha. Annual erosion rates of 20 to 25 t/ha are quite common in agricultural land that is suffering rill and gully erosion.[3] (Rill erosion occurs when the runoff is concentrated into small visible channels; eventually these deepen into gullies.)

Although a comprehensive, country-wide erosion monitoring program does not exist in Canada, specific studies of water erosion have been conducted for various crop/soil type and land/slope combinations. For example, a five-year study (1973-77) in Prince Edward Island measured annual soil losses ranging from 0.2 t/ha on a 12-per cent slope under grass sod, to 19.6 t/ha on a 12-per cent slope with potatoes grown up and down the slope. In a field study in southwestern Ontario, continuous corn harvesting on a 7-per cent slope gave an average annual soil loss of 19 t/ha over a 10-year period. In rotation with hay and oats, annual losses from the corn crop were just over 1 t/ha. In the prairie provinces, erosion per hectare from summer fallow averaged more than twice that from wheat in a wheat-fallow system and 40 times more than wheat in a 5-year rotation with oats, barley and hay.

The land most susceptible to wind erosion is southeastern Alberta and southwestern Saskatchewan. Although specific data are not available, during the dust bowl days of the 1930s, some areas were known to have been stripped entirely of topsoil — a loss of about 2 000 t/ha. Almost 20 per cent of the improved farmland of the prairie provinces appears to have been eroded by wind during that period.[3] Recently, wind erosion in the prairies has been much less of a problem, although drifting in the springs of 1976 and 1981 was particularly serious. The drought conditions experienced in the summers of 1984 and 1985 increased the risk of further wind erosion.

Sandy soils in Prince Edward Island, coupled with constant wind and relatively large percentages of land area under cultivation, make this the area at highest risk from wind erosion in Atlantic Canada. The shift from tobacco to corn on some sandy soils in southern Ontario has also increased the potential for wind erosion there.

Soil compaction occurs for several reasons, including repeated loadings by heavy machinery (particularly in wet conditions); packing smaller particles more tightly together by the vibration associated with high-speed tillage machinery; and frequent tillage practices associated with continous monoculture row-cropping. Soil compaction results in poor conditions for root growth and reduces the movement of water through the soil; this promotes runoff and water erosion. Although the problem is being investigated, relatively few measurements exist to document the extent of the problem. One area of concern is the lower mainland of British Columbia, where clay soils with a high water table are frequently worked when they are wet. In such circumstances, water stands for long periods on the surface, even with subsurface drainage.

LAND USE CHANGE

Large-scale clearing of forests and ploughing of natural grasslands accompanied the development of Canada from the seventeenth century to the early twentieth century. The process still continues to a limited extent on the fringes of the farmland areas of the Boreal Plain (e.g., the Peace River region). Present land clearance is more local than general and is usually more for immediate economic reasons than for colonization or settlement. Much public attention has been given to the loss of highly productive cropland and fruitland to urban uses, especially in the Niagara Peninsula and the Fraser Valley. Other concerns centre on the drainage of ecologically valuable wetlands for agricultural purposes.

There has, however, been a substantial decline in total farmland in eastern Canada, starting in the 1920s in the Atlantic Maritime ecozone and in the 1950s in the Mixed-Wood Plain. These losses are accounted for largely by the abandonment of marginal farms, many of them on hilly land. The land typically reverts to forest, and the fields and immature woodlands have become hospitable habitats for deer and small animals. Although there are no direct measures for the amount of land reclaimed by nature, some idea of the extent of the change can be gleaned from census data. In the Atlantic Maritime ecozone, a good half of the total original farmland identified in 1901 seems to have suffered this fate. In central Canada (largely in the Mixed-Wood Plain), the decline has been one hectare in four (see Figure 3.3, page 23).

Agriculture to Urban

Information about the conversion of actual or potential agricultural lands to urban uses during the period 1966 to 1976 is summarized, by ecozone, in Table 3.8. Work is under way on the production of comparable data for the period 1976 to 1981. The data for conversions of improved agricultural land and unimproved pasture are shown separately and then combined to give total agricultural land. In each case, the percentage of all rural land is also shown. Data showing the conversion of Canada Land Inventory (CLI) Classes 1 to 3 lands are also included. For reference purposes, the total farmland area (1976) in each ecozone is also shown. In the Pacific Maritime region, the total agricultural land converted between 1966 and 1976 amounted to just over 6 000 ha, almost 50 per cent of all rural land converted. Of the 6 000 ha, nearly 3 500 represented improved agricultural land. In 1976, the total farmland area in this ecozone amounted to 159 708 ha.

CLI Classes 1-3 are based on the soil's potential for crop production and may not reflect actual land use. Nonetheless, the classification is a good indicator of the loss of highly productive land to urban growth.

During the period of intensive urban development in the 1960s and '70s, the total loss of agricultural lands to urban use accounted for a scant one-fifth of one per cent of all farmland. Even in the Pacific Maritime ecozone, where there is little potential farmland, the conversion was only about four per cent. These figures suggest that the problem is not, in absolute terms, one of serious farmland loss. But the areas affected — especially the Niagara Peninsula and the Okanagan Valley — are some of the best fruit-producing lands in the country, and the sheer scarcity of suitable agricultural land in the Pacific Maritime must be considered. In these particular cases, the use of alternative, less productive land is clearly to be preferred if good environmental and resource planning principles are to be observed.

Wetlands to Agriculture

Conversions to agriculture, for example, by reclamation of wetlands, are poorly documented on a systematic country-wide basis. Indeed, a common defi-

nition for wetlands is lacking, and this has complicated the compilation of information from the many individual studies that have been made. One recent overall review has, however, been helpful as a basis for much of the following commentary on wetland conversions.[9]

Conversion of wetlands began with the arrival of the first settlers and continues to this day. Wetlands have been drained or dyked for several reasons: to increase productive farmland area; to provide space for urban or industrial development; and to reduce or control flooding. The conversion has proven successful in some areas, but numerous reports detail drainage schemes that have resulted in limited agricultural benefit. Wetland drainage is usually expensive, and common side-effects — such as changes in groundwater levels, water quality, downstream flooding, and microclimate, and losses of vegetation and wildlife habitat — are overlooked during planning.

For example, the Fraser River Delta in British Columbia is one of the most productive agricultural areas in Canada. Although an extensive area of the delta and estuary has been drained for agricultural purposes, the primary reason for dyking was a response to major floods in 1894 and 1948.

The grain-growing region of western Canada is characterized by an abundance of shallow wetlands — often referred to as potholes — varying in size from a fraction of a hectare to several hundred hectares. There has been intense conflict as to whether prairie wetlands should be used for wildlife habitat or for agriculture. It has been estimated that as much as 1.2 million hectares of wetland habitat have been converted to agricultural use. Individual studies have reported declines in wetland areas of about 60 per cent compared with pre-settlement areas.

In southern Ontario, more than one million hectares (or 70 per cent) of the pre-settlement wetland areas have been converted to other uses. The Point Pelee Marsh declined by 71 per cent between 1880 and the mid-1970s, and the Lake St. Clair marshes decreased by 39 per cent between 1915 and the mid-1970s. Another estimate has indicated a 27-per cent loss of wetlands in the Lake St. Clair region between 1965 and 1979.[10] As much as 43 per cent of wetlands bordering the Ontario shore of Lake Ontario may have been lost between 1789 and 1979.[13] Agricultural land drainage was found to be the most significant factor causing these changes.

In the St. Lawrence estuary, reports indicate that more than 30 per cent of the tidal marsh has been reclaimed for agriculture. In the Atlantic region there has been a long history of agricultural reclamation of tidal salt marshes — as much as 65 per cent of maritime wetlands are now dyked for agriculture.

The effects of wetland conversions vary from location to location. In some cases critical spawning and breeding habitats are lost, with a major impact on some aquatic species. In other cases, the disruption is relatively short-lived as these species find alternative habitats. In still other situations, important stopover areas for migrating birds may be lost. This will require adjustment for the species that have long traditions of following the same route year after year. On the other hand, conversion of wetland areas for agricultural purposes will create new kinds of habitats for other species. There will be an entirely different vegetative cover, which can provide both food and nesting areas for species that do not use wetland habitats.

CULTURAL PRACTICES

Other activities that affect agro-ecosystems are primarily cultural. These involve decisions taken at the individual farm level concerning such matters as the size of livestock operations, what crops to plant and what areas to seed, the advantages of monoculture practices, and the need for fertilizers and pesticides. These decisions are influenced not only by the farmer's knowledge and experience of natural factors such as soil and climate, but also by predicted market prices, the influence of current practices, local culture and beliefs, and information from agricultural advisory services. The combination of these various influences is referred to as 'cultural practices' in this report. This section presents data showing the nature of some of these practices in 1981 and the change that has taken place since 1971. Some of these cultural practices, along with the availability of better quality seed and hardier varieties, have led generally to improved crop yields. Examples of changing yield patterns covering a 30-year period are also documented.

Livestock Operations and Crop Area Data

A summary by ecozone of the number of cattle, pigs and poultry in 1981, and the percentage change since 1971, are given in Table 3.9. These two census years cannot be used to estimate annual changes because they do not represent year-to-year fluctuations in markets. The figures suggest, however, that the number of cattle has decreased in the Boreal Shield, Mixed-Wood Plain and Atlantic Maritime ecozones, remained constant in the Prairie region, and increased in the others, with little change overall. For pigs, the decreases recorded for the Boreal Plain and Prairie regions were more than offset by increases in other regions, particularly the Mixed-Wood Plain, so that overall there was a 22-per cent increase. The increase in the number of chickens overall is attributed largely to the increase recorded in the Pacific Maritime, Prairie, and Mixed-Wood Plain regions. The decrease in other poultry is accounted for by decreases in the Prairie and Mixed-Wood Plain ecozones.

A summary of selected field crops by ecozone is given in Table 3.10. These figures indicate a substantial increase in the area devoted to wheat production between 1971 and 1981 in all ecozones except

Table 3.8
Conversion of Rural Land to Urban Uses, 1966-1976

Lands Converted	Pacific Maritime	Montane Cordillera	Boreal Plain	Prairie	Boreal Shield	Mixed-Wood Plain	Atlantic Maritime	Canada
All Rural Land[1] (ha)	12 573	3 023	742	36 772	8 204	77 600	10 482	149 396
Improved Agriculture (ha)	3 471	1 167	327	26 955	1 874	47 337	1 717	82 848
% of All Rural Land	28	39	44	73	23	61	16	55
Unimproved Pasture (ha)	2 551	1 656	132	7 302	1 125	15 934	965	29 665
% of All Rural Land	20	55	18	20	14	21	9	20
Total Agriculture (ha)	6 022	2 823	459	34 257	2 999	63 271	2 682	112 513
% of All Rural Land	48	93	62	93	37	82	26	75
CLI 1-3 Lands[2] (ha)	1 385	1 734	355	26 622	1 707	58 071	3 136	93 010
% of All Rural Land	11	57	48	72	21	75	30	62
Total Farmland Area (1976) (ha)	159 708	1 660 591	11 153 278	43 818 383	1 714 503	8 162 882	1 734 097	68 425 114

[1]Data are based on eighty urban areas with populations of over 25 000 according to the 1976 census.
[2]CLI 1-3 (Canada Lands Inventory Classes 1 to 3) lands represent prime agricultural lands, i.e., the soils have no severe limitations for crops.
Source: Environment Canada, "The Urbanization of rural land in Canada: 1966-1971 and 1971-76", Land Use in Canada Series No. 20, 1981; Statistics Canada, Data on total farmland area include the Yukon and Northwest Territories and were extracted from computer files of Agricultural Census Subdivision, 1984.

Table 3.9
Summary of Number of Cattle, Pigs and Poultry by Ecozone, 1981 and % Change, 1971-1981
(thousands)

	Pacific Maritime		Montane Cordillera		Boreal Plain		Prairie		Boreal Shield		Mixed-Wood Plain		Atlantic Maritime		Canada[1]	
Livestock	1981	% Change 71-81	1981	% Change 71-81	1981	% Change 71-81	1981	% Change 71-81	1981	% Change 71-81	1981	% Change 71-81	1981	% Change 71-81	1981	% Change 71-81
Cattle	200	+22	536	+30	1 737	+25	6 093	+0.2	468	−6.9	3 941	−5.9	522	−2.4	13 502	+1.7
Pigs	171	+287	69	+213	509	−44	2 152	−31	201	+36	6 347	+80	425	+30	9 875	+22
Chickens	9 045	+26	891	+56	2 455	−18	17 213	+3.6	4 637	−0.4	52 094	+5.3	6 374	+5.8	92 718	+5.9
Other Poultry[2]	668	−8.5	101	−0.9	424	−2.7	2 191	−17	330	+1.8	5 992	−2.5	209	+59	9 915	−5.7

[1]Data for the Yukon and Northwest Territories are included in the Canada totals but are not available by ecozone.
[2]Other poultry includes turkeys, geese, ducks and other.
Source: Statistics Canada, Census of Agriculture, 1981.

the Montane Cordillera, where a small decrease was recorded. At the same time, significant decreases in the area devoted to oats were recorded for all ecozones except the Montane Cordillera, where some increase was recorded. In the case of canola, the recorded decrease overall and in the two principal production areas (Boreal Plain and Prairie) is believed to be an artifact; special incentives in 1971 resulted in unusually large production that year. Agricultural experts indicate that there has been a steady, continuous growth in the production of canola. All other crops included in the table recorded increases between 1971 and 1981, with grain corn and soybeans showing changes of 99 and 89 per cent respectively. The Mixed-Wood Plain region showed the only decrease in tame hay, and this nearly counterbalanced increases in other regions.

Monoculture Practice

Monoculture cropping is the practice of growing a single crop type year after year without the benefit of crop rotation. A monoculture farm is defined as one where 80 per cent of the cropland area is used for a single crop. The absence of crop rotation contributes to the decline of organic matter content and soil nutrients. It also contributes to increased susceptibility to damage from pests and disease, which tend to

flourish in a single-crop environment. This, in turn, requires more intense application of herbicides and insecticides. When the monoculture is a wide-row crop (e.g., corn, soybeans), there is increased risk of soil loss due to erosion, particularly water erosion. For close-row crops (e.g., wheat, oats, barley), wind erosion is a serious problem in times of drought.

The extent of monoculture practice, and the change since 1971, is shown in Table 3.11. In some regions, monoculture does not affect a large fraction of the total cropland area (for example, Montane Cordillera) but in others (Prairie), it is very large (about 75 per cent). More important, in those regions where monoculture is relatively large, there were increases between 1971 and 1981 ranging from about 10 per cent (close-row monoculture, Prairie) to over 70 per cent (wide-row monoculture, Mixed-Wood Plain).

Fertilizers and Pesticides

Data on the use of fertilizers and pesticides are summarized, by ecozone, in Table 3.12. Substantial increases were recorded in the amount of land fertilized in all regions. Although data on the application rate (kg/ha) were not available for 1971, the 1981 data show that the highest rate (627 kg/ha) occurred in the Pacific Maritime region and the lowest in the Prairie (125 kg/ha) and Boreal Plain (137 kg/ha) regions. Judging from data already presented (Figure 3.2), showing the rapid increases in fertilizer sales in Saskatchewan, Manitoba and Alberta between 1970 and 1977, the relative application rates have changed significantly with time.

Overall, there were also large increases in the areas treated with herbicides and insecticides (about 80 per cent in each case). About 10 times as much area is treated with herbicides as with insecticides. The Prairie region accounts for two-thirds of the total Canadian area treated with herbicides and more than half of the area treated with insecticides. All regions, with the exception of the Montane Cordillera and the Pacific Maritime, recorded major increases in the areas treated with herbicides and insecticides.

Some pesticides have damaging effects on non-target organisms; others are persistent and may accumulate in the food chain and pose a risk to human health. Some insects have built up a resistance to pesticides. Attention is now being focused on integrated pest management methods incorporating biological and other control agents; if successful, these should gradually reduce the reliance on chemical control procedures.

Genetic Diversity

The manipulation of genetic material and the potential loss of cultivar species is of world-wide concern.[8] Authorities have pointed to the vulnerability of genetically manipulated, high-yield strains and their consequent need for more intensively controlled growing conditions (e.g., susceptibility to climate shock or nutrient deficiency). Protecting genetic stocks is, therefore, a form of insurance policy against natural disaster — a strong argument for maintaining species diversity in the natural state.

A broad genetic base is needed if breeding programs are to achieve improvements in yields; varieties better adapted to short, cool seasons; better nutritional qualities; and improved resistance to pests and diseases. Because of intensive selection for high performance and uniformity, the genetic base of much modern food production has grown dangerously narrow. Only four varieties of wheat produce 75 per cent of the crop grown on the Canadian prairies; 72 per cent of United States potato production depends on only four varieties; and two varieties supply commercial pea production in the United States.

The useful lifetime of a given crop variety depends on many factors, such as the development of resistant strains of pests and disease, changing soil conditions, and consumer preferences. Awareness of this has led to the growth of gene banks for the storage, preservation and breeding of plant genetic resources. Special attention is being focused on the development of grain varieties that perform well on acid soils without the need to lime, crop strains with considerably higher tolerance to salts, and cultivars that are more resistant to winter killing.

Crop Yields

Information provided so far in this chapter indicates that there was a decrease in the number of farms and in total farmland area, accompanied by increases in cropland area and improved pasture area, between 1971 and 1981. There have also been conversions of agricultural land to urban uses and of wetlands to agriculture. Several factors have contributed to changing soil quality (organic matter loss, nutrient supplies, salinization and erosion), and cropping practices have also changed during this period. The question that arises is how all these changes have affected crop production and, particularly, crop yields.*

Yield data are obtained from sampling surveys of a cross-section of farmers. Annual yields (tonnes per hectare, t/ha) are published for selected crops by crop district and by province. Reorganizing these data to represent yields by ecozone can be done by matching crop districts to ecozone boundaries. Figure 3.4 illustrates annual yields between 1953 and 1983 for the following selected crops and ecozones: fodder corn (Pacific Maritime); wheat (Prairie); and grain corn (Mixed-Wood Plain). In all cases, there was a long-term

*Yield is the measure of the actual quantity harvested divided by the area seeded. Thus, climate, disease conditions and even economic factors (e.g., low prices) influence the amount harvested. This should be distinguished from biological yields based on controlled growing conditions, i.e., potential yield.

Table 3.10
Summary of Selected Agricultural Crop Area Data by Ecozone, 1981 and % Change, 1971-1981
(hundreds of hectares)

Agricultural Crop	Pacific Maritime		Montane Cordillera		Boreal Plain		Prairie		Boreal Shield		Mixed-Wood Plain		Atlantic Maritime		Canada	
	1981	% Change 71-81	1981	% Change 71-81	1981	% Change 71-81	1981	% Change 71-81	1981	% Change 71-81	1981	% Change 71-81	1981	% Change 71-81	1981	% Change 71-81
Wheat (+ Buckwheat)	14	+70	64	−1	12 632	+104	109 659	+54	107	+122	2 592	+58	126	+39	125 195	+58
Oats (for grain and fodder)	30	−35	208	+20	4 227	−15	11 942	−43	662	−30	2 464	−49	704	−28	20 246	−38
Canola	4		5		4 727	−36	9 296	−34	8	+34	8	+1.7			14 049	−35
Grain Corn	0.5	−76	0.3	+146	58		891	+1 887	30	+137	10 412	+84	26	+76	11 417	+99
Fodder Corn	80	+146	38	+89	32		299	+400	90	+61	3 336	+13	95	+40	3 968	+24
Soybeans					2		23	+154	1.4	+387	2 801	+88	1.4	+100	2 829	+89
Vegetables	67	+10	11	+4	5	+70	61	+14	17	+43	924	+12	89	+38	1 174	+14
Tame Hay	416	+26	1 766	+35	11 355	+14	15 471	+6	3 501	+5	15 516	−11	+3 130	+3	51 155	+2
Total Cropland Area	752	+32	2 460	+31	48 857	+18	199 341	+10	5 152	+7	47 216	+10	5 831	+4	309 658	+11

Data do not include Yukon and Northwest Territories.
Data for Canada include small contributions from other ecological regions.
Source: Statistics Canada, Census of Agriculture, 1981.

Table 3.11
Summary of Cropland Area under Wide-Row and Close-Row Monoculture by Ecozone, 1981 and % Change, 1971-1981
(thousands of hectares)

Cropping Practice	Pacific Maritime		Montane Cordillera		Boreal Plain		Prairie		Boreal Shield		Mixed-Wood Plain		Atlantic Maritime		Canada	
	1981	% Change 71-81	1981	% Change 71-81	1981	% Change 71-81	1981	% Change 71-81	1981	% Change 71-81	1981	% Change 71-81	1981	% Change 71-81	1981	% Change 71-81
Wide-row Monoculture	7.2	+20	1.3	−51	0.6	+65	22.5	+226	3.5	+33.2	793	+72	16.4	−20	846	+70
Close-row Monoculture	3.2	+141	8.5	+28	2 597	+30	15 594	+8.5	25.2	+10	120	−1.0	24.5	−2.3	18 373	+11
Cropland Area	75	+32	246	+31	4 886	+18	19 934	+10	515	+7	4 722	+10	583	+4	30 966	+11

Data for the Yukon and Northwest Territories are included in the Canada totals but are not available by ecozone.
Source: Statistics Canada, Census of Agriculture, 1981, special tabulation by the Office of the Senior Adviser on Integration.

trend during this period towards increasing yields, despite considerable year-to-year variation.* The major factors in these increases are probably improved seed quality and the rise in fertilizer and pesticide use. Other factors might include more care in controlling the growing environment (e.g., irrigation, tillage techniques) and the abandonment or altered use of less suitable land.

Corn production in the Mixed-Wood Plain shows a distinct decline in the rate of yield increase since the mid-1960s. This observation conforms to the prediction of future trends in agricultural technology, based on general observations of a levelling off of yields per hectare of major food crops throughout the world since the 1970s.[12] Agricultural scientists recognize the possible fall-off of yield per unit effort and

*High wheat yields were reported in the early cultivation of the virgin prairie soils — over four tonnes per hectare. These figures declined steadily with the spread of disease (e.g., rust) and declining soil quality.

attribute it to the cumulative effects of soil degradation, use of marginal lands (e.g., those affected by periodic drought), and the vulnerability of new cultivars to disease. They predict that these factors will eventually limit further increases, and possibly cause absolute declines, in crop yields.

Environmentalists are concerned about increased dependency on chemical control and genetic manipulation, as opposed to more natural means of obtaining increased yields. These considerations must be taken into account in assessing the relationship between growth in agricultural output and the state of agro-ecosystems. Data describing the extent of organic farming in Canada are not available, but the increased number of natural food outlets in urban centres suggests the popularity of an alternative form of agriculture in Canada.

CLIMATE CONDITIONS AND CLIMATE CHANGE

The combination of soil conditions and climate has largely determined the nature and extent of agricultural practice in Canada. Some conditions are ideally suited for growing fruit (as in the Annapolis and Okanagan Valleys and the Niagara area), wheat (the Prairies), corn (southern Ontario), or potatoes (Prince Edward Island).

Soil moisture levels, precipitation and temperature (i.e., the length of the growing season) all help to determine whether there will be a poor, average or bumper crop. But timing is also important. Too much soil moisture at the beginning of the year could delay planting; a long dry spell at a critical stage in the growth cycle could lead to crop failure. Certain combinations of weather conditions can also promote or inhibit the outbreak of diseases or pests.

Most crops do have a reasonable tolerance for these variables, but year-to-year variations in yield (20 to 25 per cent is not uncommon) are attributable largely to climate. Prairie farms are particularly vulnerable to weather. Annual wheat yields in the 1952-1982 period ranged from 0.7 to 2.1 t/ha. It has been estimated that 50 to 60 per cent of the variability was due to available soil moisture.[1] An illustration of the respective patterns of annual crop yield and certain climate-related data is given in Figure 3.5. The annual wheat yields for the Prairie ecozone are shown for the period 1952-1982. Climate data for four sites (Lethbridge, Saskatoon, Regina and Brandon) were averaged to obtain a very broad indication of the climate conditions throughout the prairie region. The total available moisture for each crop year was determined by taking the soil moisture level at week 12 (the end of March) and adding to that the amount of precipitation that fell in April, May, June and July. The resulting composite figure has been plotted.

In addition, the number of growing degree days above 5°C (averaged for the four sites) has been plotted. The similarities in the shape of the yield curve and the combined moisture-precipitation curve, in particular, emphasize the importance of this parameter.

Any long-term global warming that might arise as a result of increased carbon dioxide levels (the greenhouse effect) would be expected to increase the area of land with agricultural potential in western Canada. Whether this would lead to increased overall production of wheat would, however, depend on the soil quality and the moisture and temperature regimes throughout the entire agricultural area.

ECONOMIC FACTORS

Market forces have a considerable, if indirect, effect on the state of agro-ecosystems. Changing land values, commodity prices, the cost of materials and machinery, and interest rates, along with changing social values, lead the individual farmer to decide either to sell out or to continue farming. Re-evaluating the balance sheet is a periodic necessity. The choice of crop or of livestock, and the practices and technology used or rejected, depend on access to markets, projected returns, costs of fertilizers, pesticides and fuel, and the value of farmland. A farmer's potential income depends on such factors as natural fertility, climate, location (in terms of market), good sense and sheer luck. The relative importance of all but the last two factors varies from region to region, but their impact is real. Although the question of sustainable yield is never far from the farmer's mind, efforts to cut costs in order to maintain the farm's short-term economic viability may inadvertently threaten the long-term stability of the operation.

Land and Agricultural Production Values

When farms are in proximity to major cities or cottage country, the price of land for agricultural purposes can be grossly distorted. According to the 1976 census, capital value per hectare (including farm buildings) was as high as $12 000 (near Vancouver), $7 000 (near Victoria or in the County of York in Ontario), and $6 000 (County of Middlesex, Ontario). In locations more distant from urban areas, prime farmland tended to cost about $1 000 per hectare, and less valuable land was in the range of $200 to $600.

A summary by ecozone of selected economic factors for 1981, along with the percentage change between 1971 and 1981, is provided in Table 3.13. The data include the total value of agricultural production (in constant 1971 dollars) and the value of that production per unit of productive land area. The latter figures show marked differences between the different regions, ranging from just over $80/ha in the Boreal Plain to nearly $1800/ha in the Pacific Maritime ecozone. There was very little change between 1971 and 1981 in the production value per hectare for the Montane Cordillera, but the value in all other regions increased by between 23 and 40 per cent.

Table 3.12
Summary of Agricultural Input (Fertilizers, Herbicides, Insecticides) Data by Ecozone, 1981 and % change, 1971-1981

		Pacific Maritime		Montane Cordillera		Boreal Plain		Prairie		Boreal Shield		Mixed-Wood Plain		Atlantic Maritime		Canada	
	Units	1981	% Change 71-81	1981	% Change 71-81	1981	% Change 71-81	1981	% Change 71-81	1981	% Change 71-81	1981	% Change 71-81	1981	% Change 71-81	1981	% Change 71-81
Area Fertilized	000s ha	55.0	136	133	190	2 811	138	11 313	202	184	144	3 096	111	336	104	17 929	167
Fertilizer Application Rate	kg/ha	627		233		137		125		303		415		477.3		188	
Area Treated with Herbicides	000s ha	19.6	74.2	25.7	60.1	1 948	142	10 752	68.9	44.3	186	2 272	79.5	159	71	15 220	78
Area Treated with Insecticides	000s ha	11.4	1	13.6	-24.3	191	152	891	95	11.1	110	459	63	74.3	18	1 652	81

Data do not include Yukon and Northwest Territories.
Data for Canada include small contributions from other ecological regions.
Fertilizer data do not include fertilizer applied to improved pasture (largely manure).
Data not available for fertilizer application rate for 1971.
Fertilizer application rates vary considerably from farm to farm depending on soil conditions and crop.
Source: Statistics Canada, Census of Agriculture, 1981, special tabulation by the Office of the Senior Adviser on Integration.

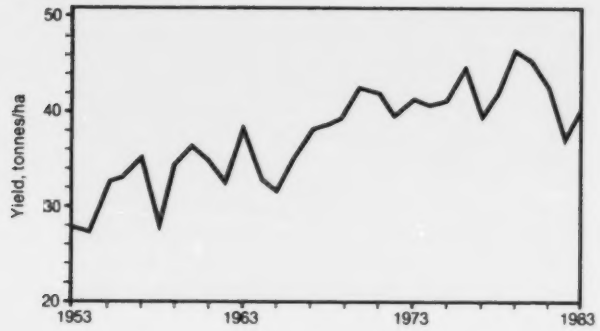
Table 3.13
Summary of Selected Economic Factors by Ecozone, 1981 and % change, 1971-1981

		Pacific Maritime		Montane Cordillera		Boreal Plain		Prairie		Boreal Shield		Mixed-Wood Plain		Atlantic Maritime		Canada	
Economic Factors	Units	1981	% Change 71-81	1981	% Change 71-81	1981	% Change 71-81	1981	% Change 71-81	1981	% Change 71-81	1981	% Change 71-81	1981	% Change 71-81	1981	% Change 71-81
Total Value Agricultural Production	000s $	185 731	40	98 419	43	463 240	62	2 503 681	57	129 965	29	2 383 329	34	234 460	30	5 999 268	45
Production Value/ Productive Land Area	$/ha	1 771.51	23	224.81	0.3	81.13	34	113.50	40	182.57	31	426.89	34	309.26	33	169.61	31
Area Fertilized	000s ha	55.0	136	133	190	2 811	138	11 313	202	184	144	3 096	111	336	104	17 929	167
Fertilizer Expenses/ Fertilized Area	$/ha	90.09	-22	19.17	-40	12.61	71	12.66	45	25.61	-29	36.34	-26	40.07	-40	17.67	-10
Area Treated with Chemicals	000s ha	31.0	239	39.3	185	2 139	501	11 643	322	55.4	559	2 731	336	233	267	16 873	340
Chemical Expenses/ Area Treated	$/ha	38.12	-59	34.27	-66	4.92	-27	4.72	6.5	12.12	-79	12.34	-65	17.54	-62	6.31	-43
Farm Fuel Expenses/ Farmland Area	$/ha	34.11	109	4.94	135	4.55	83	4.03	87	4.79	63	13.29	74	8.06	108	5.43	81

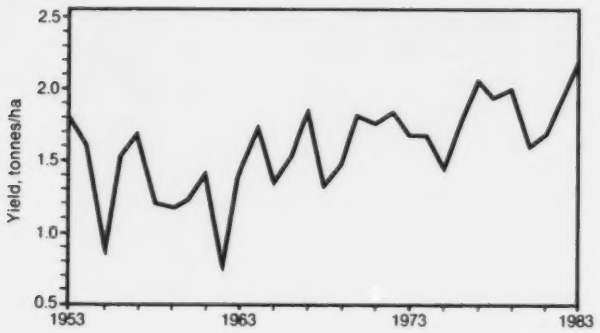
Data do not include Yukon and Northwest Territories. Data for Canada include small contributions from other ecozones not listed.
All dollar figures in constant 1971 dollars.
Conversion of 1981 value of agricultural production using 1980 farm prices of Agricultural Products Index of 263.9 (1971 = 100). Productive land = Cropland + Improved Pasture.
Conversion of fertilizer expenses based on index of 304.9. Fertilizer data do not include fertilizer applied to improved pasture (mostly manure).
Conversion of chemical expenses based on index of 336.9.
Conversion of farm fuel expenses based on index value of 249.6
Source: Statistics Canada, Census of Agriculture, 1981.

Figure 3.4
Crop Yield Data, 1953-1983

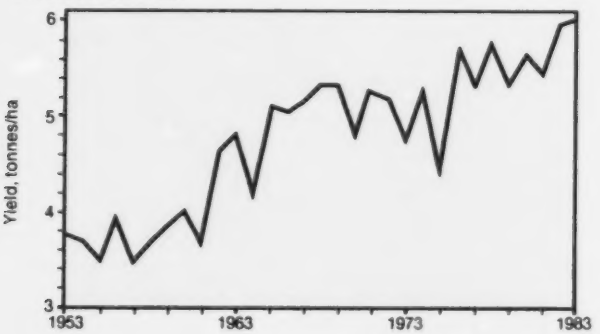
Fodder Corn
Pacific Maritime



Wheat
Prairie



Grain Corn
Mixed-Wood Plain



Source: 1952-1975: Statistics Canada, *Occasional Handbook of Agricultural Statistics*, Part I, "Field Crops", Catalogue 21-516.
1975-1983: Statistics Canada, *Handbook of Agricultural Statistics*, Revised edition, 1983.

Fertilizer, Chemical and Farm Fuel Expenses

Data concerning area fertilized, fertilizer expenses per unit area, area treated with chemicals, chemical expenses per unit area, and farm fuel expenses per unit of farmland area are also provided in Table 3.13.

A comparison of 1971 and 1981 census data on area fertilized or treated by chemicals (insecticides, herbicides or fungicides) shows a large increase in the use of farm chemicals. In the Prairie ecozone, more than three times as much land was treated with fertilizers in 1981 as in 1971, and there are still greater increases in the areas sprayed for pest control. The intensity of chemical application (as measured by average dollar per hectare) shows great variations between ecozones, from $130/ha in the Pacific Maritime region to a low of $20/ha in the vast Prairie farmland. The value of the product varies, predictably, with the cost of chemical inputs.

Farm fuel expenses per unit of farmland area also increased substantially between 1971 and 1981 in all regions, ranging from 63 per cent in the Boreal Shield to 135 per cent in the Montane Cordillera and 81 per cent overall. Actual costs in 1981 (constant 1971 dollars) ranged from $4.03/ha in the Prairie ecozone to $34.11/ha in the Pacific Maritime zone.

In 1980, about 25 per cent of total farm operating expenses was estimated to be for petroleum products, fertilizers, pesticides, electricity and heating fuel.[1] This percentage had increased from about 20 per cent in 1971.

ASSESSMENT

All agro-ecosystems are underpinned by practices and techniques to maintain soil quality and annual harvests; Canada is no exception, having inherited the European traditions of crop rotation and the use of natural fertilizers. However, in the past 30 or 40 years, we have witnessed a substantial transformation of agricultural techniques. This transformation has resulted, on one side, in increasing yields and spectacular growth in labour productivity and, on the other, in a high dependence on manufactured chemicals, fuels, heavy machinery and a narrowing gene pool. Our experience of this 'new' agriculture is not sufficiently long to draw any definite conclusion about its capability to maintain these high levels of output on a sustainable basis. This chapter has therefore examined available data to illustrate trends that are of concern from this perspective, with particular emphasis on soil quality.

The number of farms and the total amount of farmland area declined between 1971 and 1981. The average size of farms increased, however, as did the area of cropland and improved pasture. Land allocated to wide-row crops, like corn, soybeans, potatoes and vegetables, increased by about 60 per cent between

1971 and 1981, and the amount in summer fallow decreased by about 10 per cent.

Overall, climate is the greatest single factor affecting agricultural productivity in Canada. Nevertheless, the combination of crop and seed selection and farm management practices has produced, over the past 30 years, an average annual increase in yield for many crops of between about 0.8 and 1.6 per cent.

The total value of agricultural production (in constant dollars) increased by about 45 per cent between 1971 and 1981, but the total cost for inputs such as fertilizers, chemicals (herbicides and insecticides) and farm fuel (in constant dollars) increased by more than 100 per cent. The areas of fertilizer and chemical application increased by about 170 and 340 per cent respectively. The most intensively fertilized area is in the croplands of southwestern Ontario; the most rapid growth rates, however, are to be found in the Prairie ecozone.

Nearly 150 000 hectares of rural land were converted to urban use during the period between 1966 and 1976; this amounted to only about 0.2 per cent of the total farmland area. About 75 per cent of the converted land was, however, agricultural land, and more than 60 per cent was prime agricultural land. Although not so well documented, there have been substantial areas of wetlands converted to agricultural use since pre-settlement times.

A major concern is changes in soil quality. These are attributed in part to management decisions such as the shift from natural to chemical fertilizers, the extent of summer fallowing and the expansion of monoculture practice.

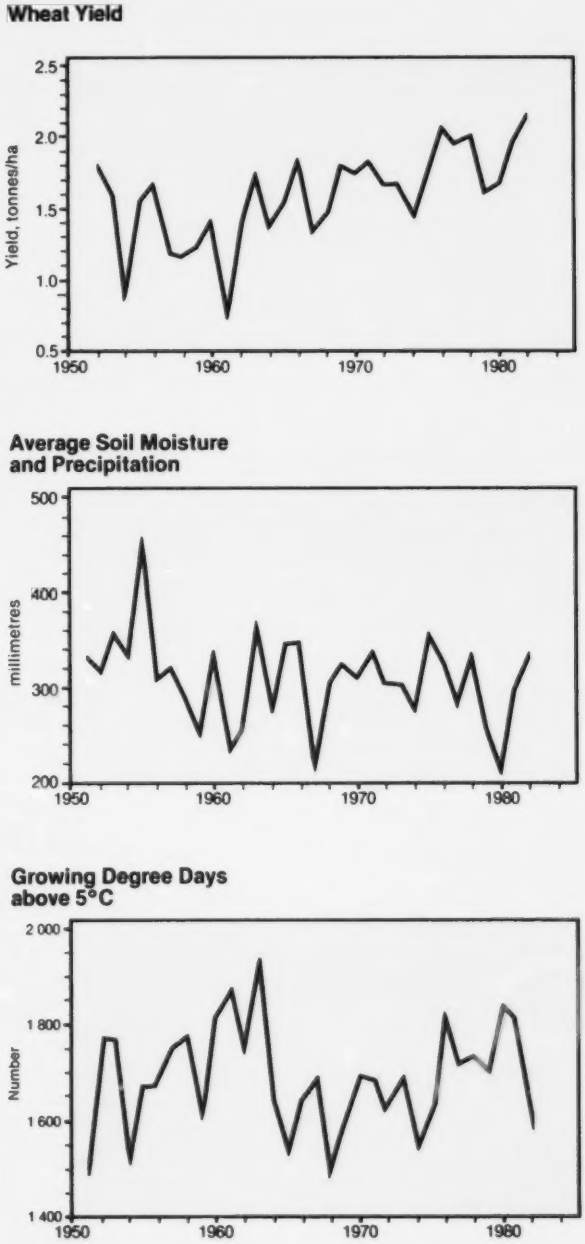
Organic matter loss increases the susceptibility of the soil to compaction and wind or water erosion, and soil that has lost organic matter may require supplemental nitrogen. The loss of organic matter in various parts of the country has been estimated to be as much as 50 per cent since cultivation began.

Major nutrients (nitrogen, phosphates and potassium) are removed during harvesting, and the conventional way of restoring the balance has been through the application of fertilizers. Studies on nutrient balance in Canadian agriculture between 1960 and 1980 show an increasing use of fertilizers, to the extent that in many areas a far greater quantity of nutrient content is now applied to the soil than is taken out by removal of crops.

Increased soil acidity, which takes place as a result of leaching and crop removal, may be accelerated by the application of nitrogen fertilizer and atmospheric deposition (acid rain). In much of eastern Canada, measurable decreases in soil pH have occurred. Some researchers attribute 40 per cent of this to acid precipitation and 60 per cent to the use of nitrogenous fertilizer.

Salinization, another natural process, is accelerated by agricultural practices, particularly in the Prairie region. Dryland salinization occurs with the planting of crops that need less water than native

Figure 3.5
Comparison of Wheat Yield, Soil Moisture/ Precipitation and Growing Degree Days, Prairie Ecozone, 1952-1982



Source: Wheat yield: Statistics Canada; Average soil moisture and precipitation: Environment Canada; Growing degree days above 5°C: Environment Canada.

vegetation and is exacerbated by summer fallowing. It has been estimated that dryland salinity may be expanding in parts of Saskatchewan and Alberta at a rate of 10 per cent per year. Salinization as a result of irrigation also occurs. Together these two forms of salinization may be causing economic losses far greater than those from erosion, nutrient loss and acidification combined. There is no technical or economically practical solution to reclaiming salinized lands.

Although soil erosion is not monitored systematically in Canada, it is thought that annual erosion rates of 20 to 25 tonnes per hectare are quite common in high-risk areas. Wide-row monoculture and summer fallowing contribute significantly to erosion potential.

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INTRODUCTION

Forests cover nearly 45 per cent of Canada's total land area. Of this, roughly one-half, or 264 million hectares (ha), is classified by the Canadian Forestry Service as productive forestland. Inventoried forestland as a percentage of total forestland is given in Table 4.1.* A further ecozone breakdown of stocked productive forestland is shown in Figure 4.1.

An examination of the state of forest ecosystems would look at measures of productivity (mean annual increment in biomass), biotic composition (degree of dominance of major tree species), size and age distributions of stands, disease incidence, recovery after disturbance, and nutrient and soil conditions.

A number of special studies by the Canadian Forestry Service provide data that may serve directly or as approximations for these indicators. In few cases are the data in a form tailor-made for an overall assessment of the state of the forests. Some data relate more to models than to actual conditions (e.g., data on mean annual increment). Provincial data differ in methodologies, definitions and survey dates. At best, much of the aggregated data based on provincial inventories must be considered approximations.

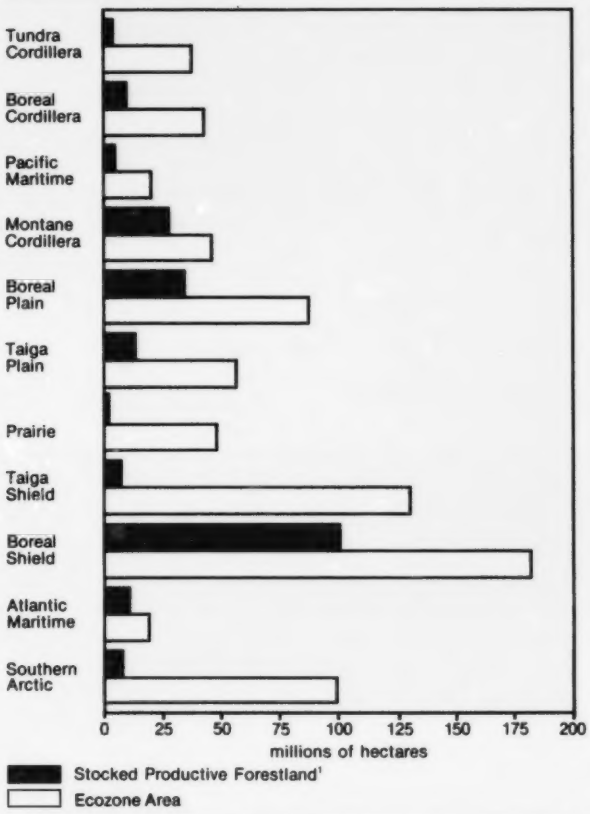
A further difficulty with forestry statistics is that some data are based on area and some on volume. There is seldom a simple way to convert one unit of measure to the other — a fact that hampers comparisons. The absence of time studies presents still more problems. This deficiency is likely to diminish with further development of the National Forest Inventory. For the moment, much of the material on forest inventory is presented as baseline data for comparison in future reports. In spite of these drawbacks, it should be possible to examine factors that affect the state of the forest and to arrive at a broad overall assessment.

Forest ecosystems are influenced by a number of factors. Some influences include fire, harvesting, physical restructuring (e.g., land-clearing for human settlement, road construction and the like), climatic change, insect and disease epidemics, and pollution. Most forests, as shown in Figure 4.2, are subject to a number of stresses, a factor that complicates and, in many cases, precludes drawing simple cause-and-effect relationships (see Figure 4.2 and Table 4.2).

The following section presents indicators of the state of the forest. These include estimates of productivity, the adequacy of regeneration after disturbance, species composition, age structure of the forest, and prevalence of diseases. We go on to describe the major influences on forest systems, quantifying where pos-

*Non-inventoried lands cover a significant portion of some regions (especially the Tundra Cordillera, Boreal Cordillera, Prairie, Mixed-Wood Plain, and Southern Arctic). However, in terms of timber volumes these regions are less important as they consist by and large of the northern transition zone between closed forest and open tundra. In the Mixed-Wood Plain, woodland interspersed with farmland is generally excluded from the national inventory. These forests are nonetheless sources of hardwoods and fuelwood. Non-inventoried sugar bush is a significant source of income in this ecozone and in the Atlantic Maritime ecozone.

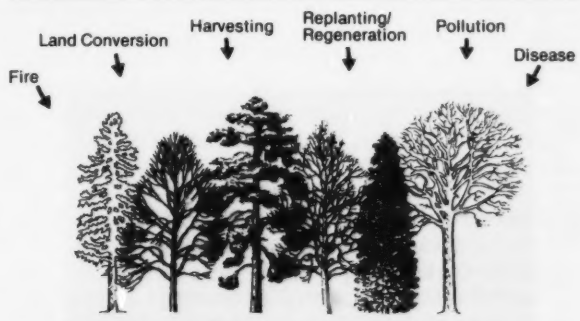
Figure 4.1
Stocked Productive Forestland in Relation to Total Ecozone Area, 1981



[1] Stocked productive forestland is forestland registered and stocked with species capable of growing to their full capacity.

Source: Environment Canada, *Canada's Forest Inventory 1981* (Ottawa: Canadian Forestry Service, 1982).

Figure 4.2
Forestry Influences and Effects: A Schematic Representation



State of the Forest Indicators
Area not sufficiently restocked
Species composition
Age distribution

sible the various stressors affecting the different forest regions. The concluding section offers a qualitative assessment of the state of the forest ecosystem.

THE STATE OF FOREST ECOSYSTEMS

Productivity

Average forest productivity can be expressed as the mean annual increment, i.e., the annual increase in size of a mature stand (Table 4.3). These values are based on models for growth under standard conditions. Intensive forest management, which involves thinning, spacing and removal of overmature and inferior trees, can substantially increase the actual growth rate.

Some lands that once bore trees of commercial sizes are now judged 'inadequately restocked'. This condition may come about from a number of causes; fire and certain harvesting practices are the usual reasons. Not sufficiently restocked (NSR) lands are often covered by inferior tree species, shrubs and lower vegetation. The area of forest designated as NSR is indicated in Table 4.4.

Each province has its own criteria as to what constitutes NSR land. Generally, such determinations depend on local knowledge of stand history and judgements by local foresters, taking into account tree density, canopy cover, and other such indicators of proper forest regeneration during the early years following disturbance. Data are not completely comparable among provinces, because different criteria have been applied in designating NSR land. The problem of data incompatibility is, of course, compounded in cases where the data from several provinces are reaggregated by ecozone as in Table 4.4. The ecozone NSR data given in Table 4.4 must therefore be considered approximate. There is, however, no question that large areas of NSR lands exist in the Boreal Shield, Boreal Plain, Taiga Plain, Montane Cordillera and Boreal Cordillera.

Table 4.1
Inventoried Forestland[1] as a Percentage of Total Forestland, 1981

Ecozone	Forestland (millions of hectares)		Inventoried Land as Percentage of Total
	Inventoried	Total	
Tundra Cordillera	15.8	37.1	43
Boreal Cordillera	22.1	40.8	54
Pacific Maritime	6.9	11.6	59
Montane Cordillera	31.7	42.0	75
Boreal Plain	50.6	62.4	81
Taiga Plain	40.8	46.0	89
Prairie	0.7	1.7	41
Taiga Shield	26.8	34.9	77
Boreal Shield	124.8	131.8	95
Hudson Bay Plain	1.6	1.6	100
Mixed-Wood Plain	3.1	5.8	53
Atlantic Maritime	12.5	14.6	86
Southern Arctic	3.7	7.4	50
Northern Arctic			
Arctic Cordillera			
Total[2]	340.8	437.6	78

[1]Inventoried forestland: forestland that has been inventoried as to the merchantable wood available.
[2]Totals may not add due to rounding.
Source: Environment Canada, *Canada's Forest Inventory 1981* (Ottawa: Canadian Forestry Service, 1982).

Biotic Composition

Approximately 150 tree species are native to Canada. Most are confined to the southern regions, especially to the Pacific and Atlantic Maritime ecozones, Mixed-Wood Plain and the eastern portion of the Boreal Shield. Only a few species prevail in the northern ecozones. This is in line with the global pattern of species distribution.

There are no readily obtainable data indicating the changes that have occurred in species composition over time. It is clear from the historical record, however, that the biotic composition has been altered significantly in some regions. For example, before European settlement, much of the southern portions of the Boreal Shield and Mixed-Wood Plain were dominated by white pine stands. Today there are only small remnants of these forests. Many northern hardwoods prevailed in the Atlantic Maritime region; these have now been supplanted in part by white spruce and other conifers.

In some regions, changes in species composition have been more subtle. For example, white spruce has often increased at the expense of red spruce in the Atlantic Maritime region. The proportion of hornbeam has increased in the agricultural woodlots of the Boreal Plain, Mixed-Wood Plain and Atlantic Maritime ecozones. It is a species avoided by cattle.

No tree species currently appears to be in danger of extinction. One possible exception is chestnut in the Mixed-Wood Plain, which has been reduced to a few specimens by a blight first observed towards the end of the last century.

Table 4.5 presents the current breakdown by major tree species, taking into account only the merchantable timber on stocked, productive, non-reserved forest lands. Much of the poplar and birch in the Boreal Shield, Mixed-Wood Plain and Atlantic Maritime ecozones can be attributed to quick growth after logging, land clearing and fire.

Table 4.2
Major Influences on Canadian Forest Ecosystems

				Physical Restructuring			*Climate-induced*	
Ecozone[6]	Fire	Insects and Diseases	Harvesting[1]	Conversion of Forest to Agriculture and Other Uses[2]	Utility/ Transport Corridors[3]	Pollution	Redbelt[4]	Windthrow[5]
Boreal Cordillera	■		■	■	■			
Pacific Maritime		■	■	■	■			
Montane Cordillera	■	■	■	■	■		■	■
Boreal Plain	■		■	■	■		■	
Taiga Plain	■		■		■			
Taiga Shield	■							
Boreal Shield	■	■	■	■		■		■
Mixed-Wood Plain		■		■		■		
Atlantic Maritime	■	■	■	■		■		■

[1]Harvesting practice includes direct effects of cutting, as well as forestry management practices such as clearcutting, full-tree logging, construction of logging roads, etc.
[2]Includes shift in land use between forest and agriculture, urban, mining, and reserves for parks.
[3]Includes seismic lines, particularly significant consumers of forestland in the Boreal Plain.
[4]Redbelt is a climatically induced mortality in conifers, caused by drying chinook winds. Lodgepole pine is particularly vulnerable.
[5]Windthrow occurs commonly in spruce stands in the Montane Cordillera and black spruce stands in the Boreal Shield, especially at the edge of stand clearings.
[6]The ecozones not included in this table have either little forestry activity or no extensive forested area.

Age Structure

The age structure of a forest provides a useful indicator of disturbance. Table 4.6 presents a breakdown of area data by age classes and ecozone. Note that large areas are classified as 'regeneration' or 'immature'. Few zones have large areas of mature or overmature timber. For example, the large white pine stands in the Ottawa Valley are gone, as are most of the 300- to 600-year-old Douglas fir stands in the Pacific Maritime ecozone. Logging and settlement have played a major role in removing these old-growth forests. Regenerating and immature forests cover an area that swings down across the Tundra Cordillera, the Boreal and Taiga Plains and the east-central parts of the Boreal Shield. The loss of mature timber in this region is attributable to natural causes, as the area coincides with some of the worst fire-weather zones.

The data presented in Tables 4.5 and 4.6 provide a baseline against which future changes can be judged. A high proportion of inventoried forests classified as regenerating or immature may indicate intense harvesting and fire stresses. Growth in the area classified as mature and overmature may reflect relaxation of these pressures. Unfortunately, no standards are yet available as to what constitutes a healthy or acceptable age distribution for each zone.

Insects and Diseases

Incidences of forest pests and diseases are further indicators of the state of forest ecosystems, particularly when the disease or insect infestation is related to stress from human activity.[2] One must be careful to compare similar stands of the same age classes, as forest insects are often stand- and age-specific. Destructive insects and diseases are monitored systematically by the Canadian Forest Insect and Disease Survey, and detailed annual reports are available.

Estimates of the total area of defoliation and the extent of forests with dead and dying trees are given in Table 4.7. The spruce budworm is by far the most serious pest, particularly in Ontario, Quebec and New Brunswick.

Budworm epidemics are apparently a cyclical phenomenon, as the history of budworm infestation in eastern North America suggests (Figure 4.3). During the present century there have been three distinct episodes of heavy infestation: 1910-1920, 1940-1957, and 1970 to the present. The current episode is by far the most extensive (Figure 4.4).

Dutch elm disease is of more recent origin, having first made its appearance in Canada some 40 years ago. The disease is responsible for the death of elm

Table 4.3
Estimated Mean Annual Increment[1] of Canadian Forests, by Ecozone, 1981
(cubic metres/hectare)

Ecozone	Mean Annual Increment
Tundra Cordillera	0.4
Boreal Cordillera	1.3
Pacific Maritime	4.0
Montane Cordillera	1.9
Boreal Plain	1.8
Taiga Plain	0.8
Prairie	1.2
Taiga Shield	0.4
Boreal Shield	1.5
Hudson Bay Plain	0.8
Mixed-Wood Plain	2.2
Atlantic Maritime	1.9
Southern Arctic	0.3

[1]Mean annual increment (MAI): The average annual increase in diameter, basal area, height, or volume, of a forest stand. Estimates for MAI are derived from various sources including remote sensing, ground sampling, and modelling. These figures are ballpark figures based on assumptions of standard growing conditions over varying periods of time. Actual growth varies considerably from site to site depending on local environment and harvesting practices.

Source: Environment Canada, *Growth of Forests in Canada*, Part 2, "A Quantitative Description of the Land Base and the Mean Annual Increment, 1981" (Ottawa: Canadian Forestry Service, 1981).

Table 4.4
Not Sufficiently Restocked (NSR) Land[1] by Ecozone, 1981

Ecozone	Total Forestland	NSR Land	NSR Land as a Percentage of Total
	millions of hectares		%
Tundra Cordillera	37.1	0.22	0.6
Boreal Cordillera	40.8	1.83	4.5
Pacific Maritime	11.6	0.16	1.4
Montane Cordillera	42.0	1.43	3.4
Boreal Plain	62.4	7.26	11.6
Taiga Plain	46.0	1.14	2.5
Prairie	1.7	0.05	2.9
Taiga Shield	34.9	0.41	1.2
Boreal Shield	131.8	9.40	7.1
Hudson Bay Plain	1.6	0.06	3.7
Mixed-Wood Plain	5.8	0.19	3.3
Atlantic Maritime	14.6	0.43	2.9
Total[2]	437.6	22.6	5.2

[1]Land designated "not sufficiently restocked" (NSR) is land that formerly had merchantable timber but has not recovered sufficiently after disturbance due to fire, harvesting, insect damage or other stresses.

[2]Totals may not add due to rounding.

NSR lands are concentrated in harvested areas. An interesting comparison, for which there are no readily available data, would be NSR land as a percentage of lands harvested 5 to 20 years ago. See other qualifications in text.

Source: Environment Canada, *Canada's Forest Inventory 1981* (Ottawa: Canadian Forestry Service, 1982).

populations, especially in the urban and agricultural landscape of the Mixed-Wood Plain and Atlantic Maritime zones and, to a lesser degree, in the southern portions of the Boreal Shield and Boreal Plain. The dramatic spread of this disease (which probably originated in Asia) is shown in Figure 4.5. Although the elm population does not appear to be in danger of extinction, owing to its rapid growth and large seed supply, the death of elms has dramatically altered, at least temporarily, the appearance of urban/agricultural landscapes. There are indications that elms are repopulating some regions of the Mixed-Wood Plain.

The mountain pine beetle is active largely in the Montane Cordillera, where it has been recorded since 1910. There it destroys the larger pines. Infestations are episodic, lasting up to a decade. This forest pest killed some 14 million trees in 1979, 19.6 million trees in 1980, and over 32 million trees in 1981. The number of mature trees killed is shown in Figure 4.6, and the areas of infestation are shown in Figure 4.7.

Canadian forests, characterized by even-aged stands (largely due to periodic fires) and monocultures, provide ideal conditions for the outbreak of insect and disease epidemics. The estimated average annual depletion of forests by insects and diseases over the period 1977-1981 is given in Figure 4.8. Spruce budworm accounts for well over one-third of the total average annual depletion of the forests due to infestation, which in recent years has exceeded 100 million cubic metres of wood annually.

INFLUENCES ON THE STATE OF FOREST ECOSYSTEMS

Forests are altered by many processes, acting singly, synergistically and, occasionally, antagonistically. Each process has a unique mode of action and often an identifiable impact — e.g., the removal of trees of economic importance, weakening or death of trees susceptible to disease, etc.

No attempt has been made to convert these influences to common terms, and in many cases this is clearly not possible. Nor can one create models of the complex ways in which several influences might

Table 4.5
Standing Wood Volume[1] by Species and Ecozone, 1981
(millions of cubic metres)

Ecozone	Spruce	Pine	Fir	Hemlock	Cedar	Douglas Fir	Unspecified Conifer	Poplar	Birch	Maple	Unspecified Broadleaf	Total[2]
Tundra Cordillera	0	0	0	0	0	0	72	0	0	0	17	89
Boreal Cordillera	314	146	124	6	0	0	81	38	2	0	18	731
Pacific Maritime	153	35	370	909	455	154	113	16	3	4	20	2 232
Montane Cordillera	1 224	1 387	810	225	146	448	52	124	22	0	0	4 438
Boreal Plain	746	496	39	0	0	6	105	986	26	1	18	2 424
Taiga Plain	52	4	10	0	0	0	241	51	2	0	114	475
Prairie	5	3	0	0	0	0	0	16	1	0	2	27
Taiga Shield	31	4	9	0	0	0	274	1	1	0	16	337
Boreal Shield	3 248	920	1 066	30	100	0	72	937	804	297	94	7 568
Hudson Bay Plain	35	3	1	0	0	0	0	3	1	0	0	44
Mixed-Wood Plain	20	4	42	6	10	0	1	16	28	68	17	212
Atlantic Maritime	255	32	221	14	45	0	6	49	56	119	46	843
Southern Arctic	0	0	0	0	0	0	12	0	0	0	0	12
Total[2]	6 084	3 035	2 692	1 190	757	608	1 030	2 238	947	489	362	19 432

[1]Includes stocked forestland (land supporting tree growth. In this context, tree growth includes seedlings and saplings); productive forestland (capable of producing a merchantable stand within a reasonable length of time); and non-reserved land (forestland that by law or policy is available for the harvesting of forest crops).
[2]Totals may not add due to rounding.
Source: Environment Canada, *Canada's Forest Inventory 1981* (Ottawa: Canadian Forestry Service, 1982).

interact to bring about change in the character of the forest. Carefully chosen environmental indicators serve, however, to integrate the effects of the various stresses.

Fire

Fire has a major influence on the state of Canadian forests, particularly in the northern forests. These forests are fire-dependent, deriving their long-term vigour and faunal and floral diversity from repeated fire episodes.

Some species, such as jack pine, are totally dependent on fire for the release of seed to assure continued regeneration. In the absence of fire, mature stands of jack pine decay, and a natural succession to spruce species occurs.

In the short run, fires have resulted in catastrophic economic losses in timber values and temporary destruction of natural beauty and wildlife habitat. Repeated fires on shallow soils or in northern or mountainous regions (those only marginally suitable for forests) often lead to permanent soil and site degradation.

A summary of areas burned since 1960 is provided in Table 4.9. The largest burns (by area) are in British Columbia, the prairie provinces and the territories. These are also the regions where the largest percentage of forest is lost to fire (Table 4.8). Weather conditions are no doubt a major contributing factor to the severity of the major burns. Indeed, most forested areas of Canada have a moderate to high fire-weather index.*

The causes of fire, so far as they can be determined, are shown in Table 4.10. Lightning appears by far the most important cause, if the area burned is used as a unit of measure. In New Brunswick, Nova Scotia and Prince Edward Island the effect of human settlement is dominant. Forests are easily accessible, and there are more opportunities for both man-made

*The fire-weather index is a numerical rating based on meteorological measurements such as wind speed, moisture content and drought conditions. For further details see *Structure of the Canadian Forest Fire Weather Index*, published by the Canadian Forestry Service (see reference #4).

Table 4.6
Area of Stocked, Productive, Non-reserved Forestland by Age Class and Ecozone, 1981[1]
(millions of hectares)

	Age Class						
Ecozone	**Regeneration**	**Immature**	**Mature**	**Overmature**	**Uneven aged**	**Undetermined**	**Total**
Tundra Cordillera	0.5	1.7	0.5	..	0	..	2.7
Boreal Cordillera	1.2	3.0	3.6	0	..	..	7.8
Pacific Maritime	0.2	0.9	3.7	0	..	0	4.8
Montane Cordillera	0.7	10.6	14.2	0.1	0.2	..	25.8
Boreal Plain	2.8	13.1	4.0	0.7	..	5.4	26.0
Taiga Plain	0.6	6.5	3.5	..	..	0	10.6
Prairie	..	0.2	0.1	..	0	..	0.3
Taiga Shield	0.4	2.4	0.7	0.1	0	4.4	8.0
Boreal Shield	8.6	41.1	31.9	4.7	0	3.9	90.2
Hudson Bay Plain	0.1	0.2	0.2	0.2	0	0	0.7
Mixed-Wood Plain	0.5	1.6	0.6	..	0	0	2.7
Atlantic Maritime	0.3	3.8	5.3	0.4	0.3	0	10.1
Southern Arctic	..	..	0.3	0	0	..	0.3
Total	15.9	85.1	68.6	6.2	0.5	13.7	190.0

[1]This table represents 56 per cent of the total inventoried forestland.

Regeneration: The renewal of a forest crop by natural or artificial means. Also the new crop so obtained. The new crop is generally less than one metre in height.

Immature: In even-aged management, those trees or stands that have grown past the regeneration stage, but are not sufficiently developed to be harvestable (except for thinning operations).

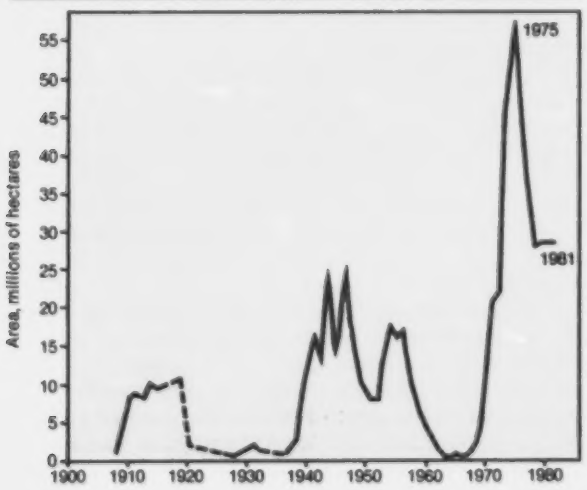
Mature: Stands or forest types at or near rotation age. Growth has culminated.

Overmature: Stands or forest types past rotation age. Openings in canopy as a result of mortality becoming apparent.

Uneven-aged: Stands or forest types in which intermingling trees differ markedly in age. The minimum difference in age permitted in an uneven-aged stand is usually 10-20 years.

Source: Environment Canada, *Canada's Forest Inventory 1981* (Ottawa: Canadian Forestry Service, 1982).

Figure 4.3
Area of Moderate or Severe Infestation by Spruce Budworm in Eastern Canada and Maine, 1909-1981



Source: Environment Canada, *A Cartographic History of Spruce Budworm Defoliation, 1967 to 1981, in Eastern North America* (Ottawa: Canadian Forestry Service, 1982).

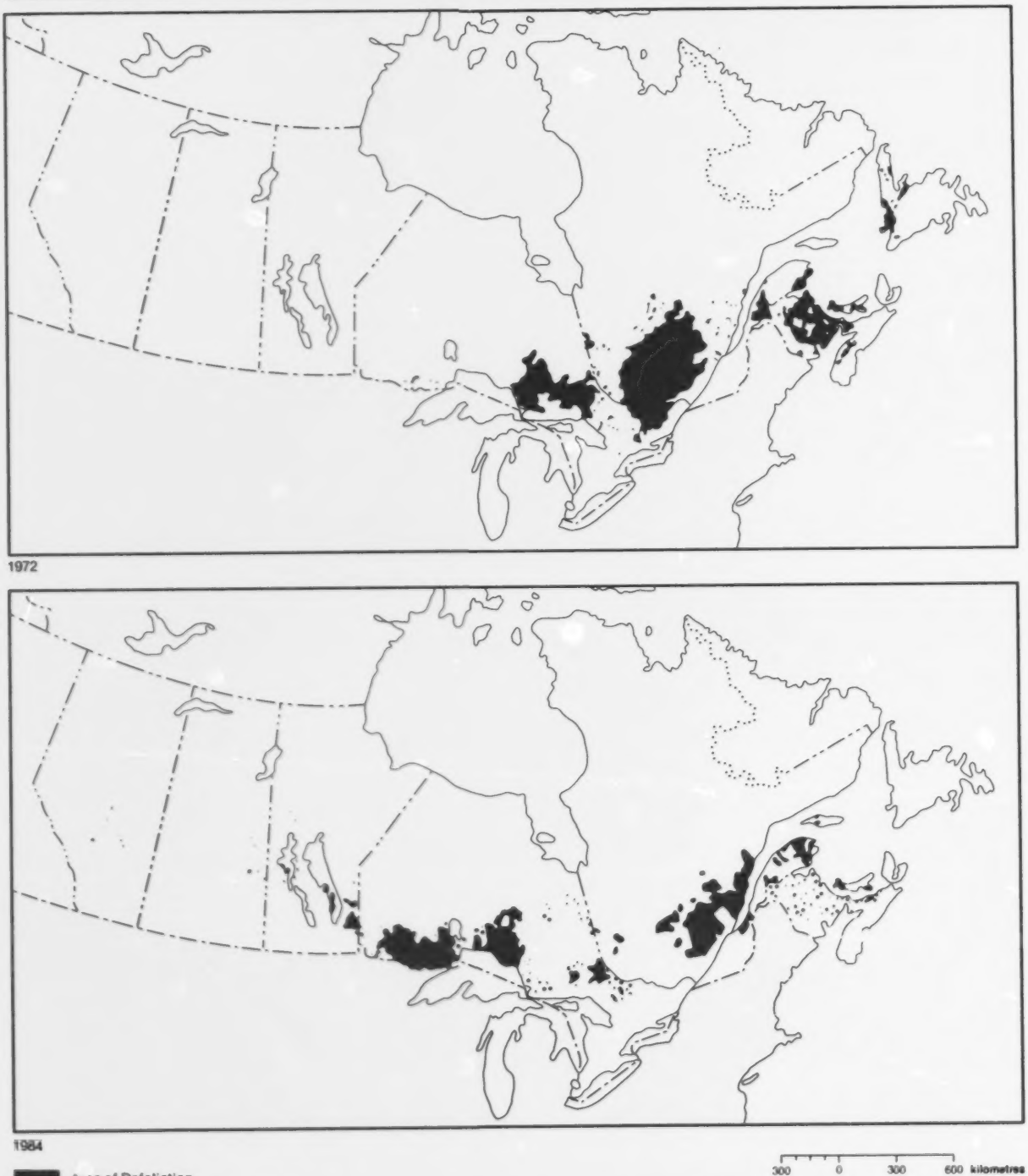
Table 4.7
Insect Damage to Forest Trees, 1983
(thousands of hectares)

Province	Area of defoliation[1]	Area with dead and dying trees
British Columbia	776	509
Prairie Provinces	75	0
Ontario	9 040	12 119
Quebec	12 266	11 964
New Brunswick	2 329	1 000
Nova Scotia	358	800
Prince Edward Island	26	30
Newfoundland	67	458
Total	24 937	26 880

[1]Extent of the pest insect infestation may be significantly greater than area of defoliation.

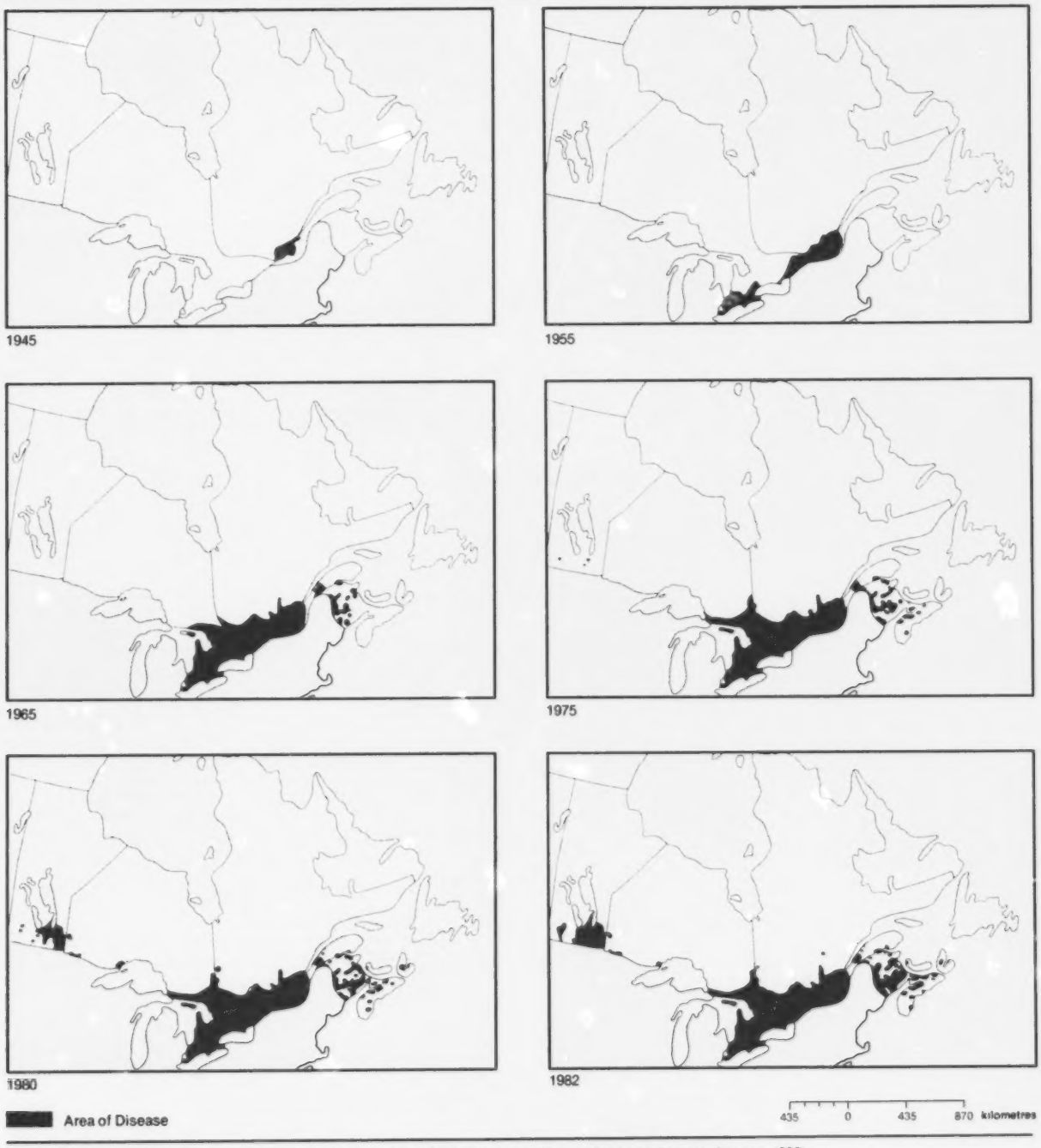
Source: Environment Canada, *Annual Pest Control Forum Proceedings* (Ottawa: Canadian Forestry Service, 1983).

Figure 4.4
Areas of Moderate to Severe Defoliation by the Spruce Budworm in Canada, 1972 and 1984



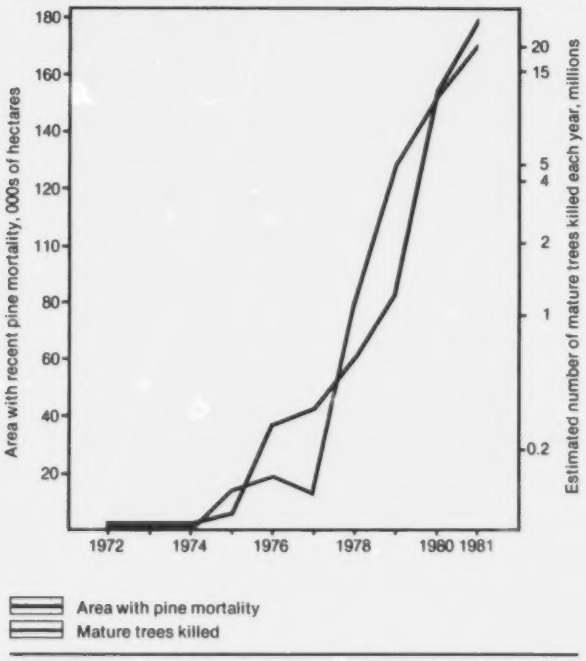
Source: Environment Canada, *Forest Insect and Disease Conditions in Canada 1984* (Ottawa: Canadian Forestry Service, 1985).
Environment Canada, *A Cartographic History of Spruce Budworm Defoliation, 1967 to 1981, in Eastern Canada and Maine* (Ottawa: Canadian Forestry Service, 1983).

Figure 4.5
Spread of Dutch Elm Disease in Canada, 1945-1982



Source: Environment Canada, *Forest Insect and Disease Conditions in Canada* (Ottawa: Canadian Forestry Service, 1982).

Figure 4.6
Pine Tree Mortality by the Mountain Pine Beetle, 1974-1981



Source: Environment Canada, *Forest Insect and Disease Conditions in Canada* (Ottawa: Canadian Forestry Service, 1983).

fires and quick suppression.

There is a tendency for fire losses to be concentrated in cutover areas and lands not covered by merchantable timber, many of which lie north of the commercial tree zone (Table 4.11).* Cutover lands burn far more frequently than areas covered by mature timber or young trees, because of the drier conditions created by timber harvest. It should be noted that fires in such timberland may be allowed to burn themselves out. Repeated burning may pose the risk of soil deterioration in some deforested lands.

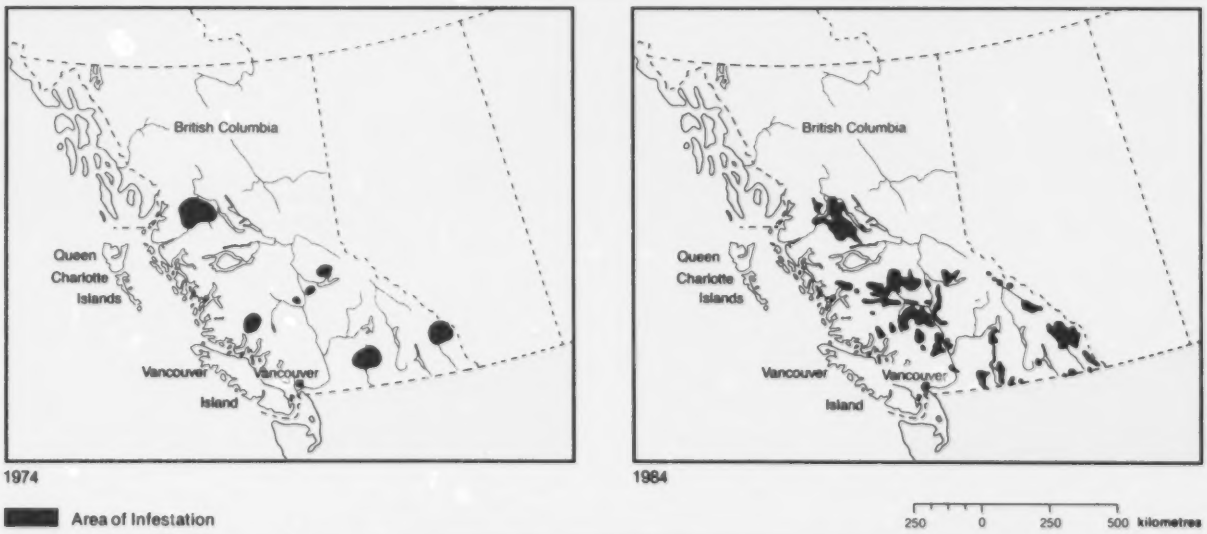
Harvesting and Forest Management

Harvesting Activities

The forest is affected by harvesting in a number of ways. Felling may directly alter the biotic composition by preferential removal of economically valued species. Forest management practices such as clearcutting, fire

*Other lands consist of shrubland, willow, tundra and heathland. Much of the fire losses indicated in the last columns of Table 4.11 are a result of the 'let burn' policy with respect to these lands, many of which lie north of the commercial tree zone.

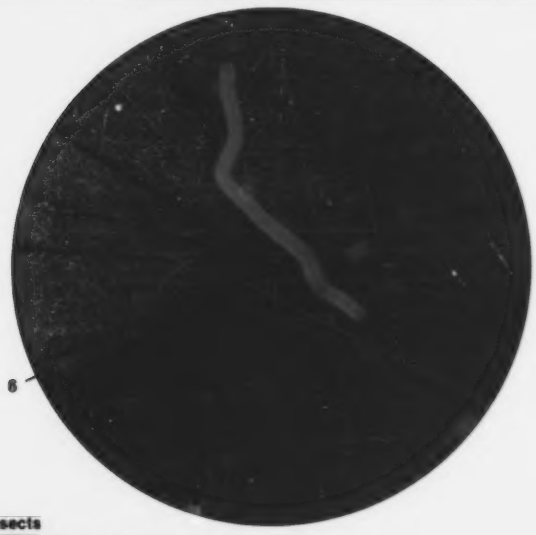
Figure 4.7
Areas of Infestation of Mountain Pine Beetle, 1974 and 1984



Data are based on aerial surveys of tree mortality.

Source: Environment Canada, *Annual Report of the Forest Insect and Disease Survey, 1974* (Ottawa: Canadian Forestry Service, 1975).
Environment Canada, *Forest Insect and Disease Conditions in Canada 1984* (Ottawa: Canadian Forestry Service, 1985).

Figure 4.8
Estimated Average Annual Depletion of Forest Caused by Major Pests, 1977-1981
(area of the pie equals 107 million cubic metres)



Source: Environment Canada, *Forest Insect and Disease Conditions in Canada 1981* (Ottawa: Canadian Forestry Service, 1982).

control, spraying, full-tree logging, and replanting also exert indirect influences on future forest productivity and its ability to support wildlife. A few of the main factors are touched on here.

To support one of Canada's leading industries, large volumes of wood are removed annually. The total amount of wood harvested has increased by 50 to 60 per cent over the past 30 years. Figure 4.9 shows the increase in roundwood production, as well as the cyclical nature of the industry, which is tied closely to the business cycle. This growth has been accompanied by a dramatic shift in the share of production coming from British Columbia. British Columbia's production has nearly tripled, and its share of the national harvest went from 27.5 per cent in 1950 to 48 per cent in 1980. During this period, eastern Canada's contribution (largely from the Boreal Shield) declined from 55 per cent to 37.4 per cent of the national harvest.

The direct stress that harvesting places on the forest depends in large part on whether removals are replaced, through either natural regeneration or plantings. When removals exceed replacement, harvesting results in a long-term depletion of the standing stock.

Is the forest being over-harvested? The data provide conflicting evidence. The provinces designate the annual allowable cut — theoretically the amount that would balance the annual growth. Inspection of these data shows that harvesting is substantially below the allowable cut in hardwoods (Table 4.12). In softwoods (Table 4.13), the harvest is nearly equal to the allowable cut and, in some provinces (Nova Scotia, New Brunswick and British Columbia), may exceed it.

The data shown in Tables 4.12 and 4.13 must be interpreted with caution. First, provincial statistics cannot be compared directly, because each province employs a somewhat different method of arriving at a value for the allowable cut. Second, and more critical,

Table 4.8
Area Burned as a Percentage of Total Forest by Region, 1960-1980

Region	Total Area Forestland 000s hectares	Year 1960	1961	1962	1963	1964	1965	1966	1967	1968	1969	1970	1971	1972	1973	1974	1975	1976	1977	1978	1979	1980
B.C., Yukon, N.W.T.	142 300	◒	◓	□	□	◒	□	◓	◒	◒	◓	◒	◓	◒	◓	□	◓	◓	◓	◒	■	■
Prairie Provinces	69 400	◓	■	◒	◒	■	□	□	◓	◓	◒	■	◒	◓	◓	◓	◒	◓	◓	◒	◓	■
Ontario	43 200	□	■	□	□	□	□	□	□	□	□	□	◒	□	□	■	□	■	■	□	◒	■
Quebec	62 400	□	□	◓	□	□	□	□	◒	◒	□	□	◓	◒	◓	◒	□	■	□	□	□	□
Atlantic Provinces	25 200	◒	■	◒	□	◓	□	□	■	□	□	□	□	◒	□	◒	◓	■	□	□	◒	□

□ less than 0.10%
◒ between 0.10 and 0.25%
◓ between 0.25 and 0.75%
■ greater than 0.75%

Source: Environment Canada, *A Statistical Study of Area Burned by Wildfire in Canada 1953-1980*, Information Report P1-X-16 (Ottawa: Canadian Forestry Service, 1982).

Table 4.9
Area Burned and Percentage of Total Forest Burned
(thousands of hectares)

	British Columbia, Northwest Territories, Yukon		Prairies		Ontario		Quebec		Atlantic	
	000s ha	%	000s ha	%	000s ha	%	000s ha	%	000s ha	%
Provincial Forestland	142 300		89 400		43 200		62 400		25 200	
1960	162	.11	346	.50	12	.03	51	.08	47	.19
1961	832	.59	1 898	2.73	479	1.11	24	.04	432	1.71
1962	37	.03	78	.11	5	.01	199	.32	27	.11
1963	31	.02	78	.11	19	.04	34	.05	4	.02
1964	193	.14	809	1.15	9	.02	20	.03	150	.60
1965	130	.09	28	.04	8	.02	17	.03	14	.06
1966	399	.28	43	.06	5	.01	8	.01	3	.01
1967	235	.16	209	.39	25	.06	109	.17	252	1.00
1968	250	.18	478	.69	2	.00	131	.21	14	.06
1969	809	.57	115	.17	2	.00	1	.00	10	.04
1970	293	.20	621	.90	22	.05	31	.05	11	.04
1971	1 056	.74	157	.23	42	.10	262	.42	4	.02
1972	315	.22	273	.39	32	.07	105	.17	50	.20
1973	889	.62	272	.39	3	.00	162	.26	10	.04
1974	53	.04	205	.30	523	1.21	101	.16	56	.22
1975	691	.48	123	.18	13	.03	27	.04	180	.71
1976	731	.51	202	.29	547	1.27	507	.81	218	.87
1977	601	.42	222	.32	417	.97	56	.09	12	.05
1978	135	.10	124	.18	3	.01	9	.01	8	.03
1979	2 019	1.42	505	.73	64	.15	7	.01	34	.13
1980	1 371	.96	1 773	2.56	557	1.29	31	.05	5	.02

Source: Environment Canada, *A Statistical Study of Area Burned by Wildfire in Canada 1973-1980* (Ottawa: Canadian Forestry Service, 1982). Environment Canada, *Canada's Forest Inventory 1981* (Ottawa: Canadian Forestry Service, 1982).

the validity of the calculation of annual allowable cut is challenged by seasoned industry observers. In 1980, for example, governments calculated that 228 million cubic metres of timber could be cut (Tables 4.12, 4.13). In the same year, only 159 million cubic metres were harvested.

Industry observers claim that the apparent surplus is illusory. They assert that the allowable cut is based on inaccurate surveys and does not take into account the unexpected loss of about 100 million cubic metres per year to fire, insects and disease. A 1976 study of Ontario offers partial support for these claims. In this case, forest inventories, based on aerial photographs, led to estimates of wood that were one-third higher than the actual amount available for cutting. The allowable cut may be valid for a well managed forest, but the formula does not give consistent results for mismanaged forests made up of lower quality trees.

These considerations might in part explain an apparent contradiction: while the total amount of wood harvested is significantly below the allowable cut, regional wood shortages are increasing. In most areas, logging is now carried out at a considerable distance from the mill; in some instances wood is hauled up

Table 4.10
Percentage[1] of Fires by Cause, 1970-1979

Province/Territory	Human Causes	Lightning	Unknown
British Columbia[2]	37	63	..
Alberta	15	84	1
Saskatchewan	14	86	..
Manitoba	34	61	5
Ontario	9	91	..
Quebec	53	40	7
New Brunswick	73	10	17
Nova Scotia	41	2	59
Prince Edward Island	73	0	27
Newfoundland	12	87	1
Yukon	0	97	3
Northwest Territories	3	95	2
Canada	11	87	2

[1]Percentage based on total area burned.
[2]Totals may not equal 100 per cent.
Source: Environment Canada, *Canadian Forest Fire Statistics, 1980* (Ottawa: Canadian Forestry Service, 1982).

Table 4.12
Allowable Annual Cut and Harvest of Hardwoods, 1979
(thousands of cubic metres)

Province	Allowable Annual Cut[1] 1979	Harvest (Average 1979-1980)	Allowable Cut less Harvest
Newfoundland	NA	24	NA
Prince Edward Island	NA	122	NA
Nova Scotia	1 404	527	877
New Brunswick	2 665	1 440	1 225
Quebec	14 000	4 067	9 933
Ontario	15 802	3 972	11 830
Manitoba	2 271	217	2 054
Saskatchewan	4 156	410	3 746
Alberta	13 531	78	13 453
British Columbia	NA	226	NA
Canada	54 201	11 083	43 118

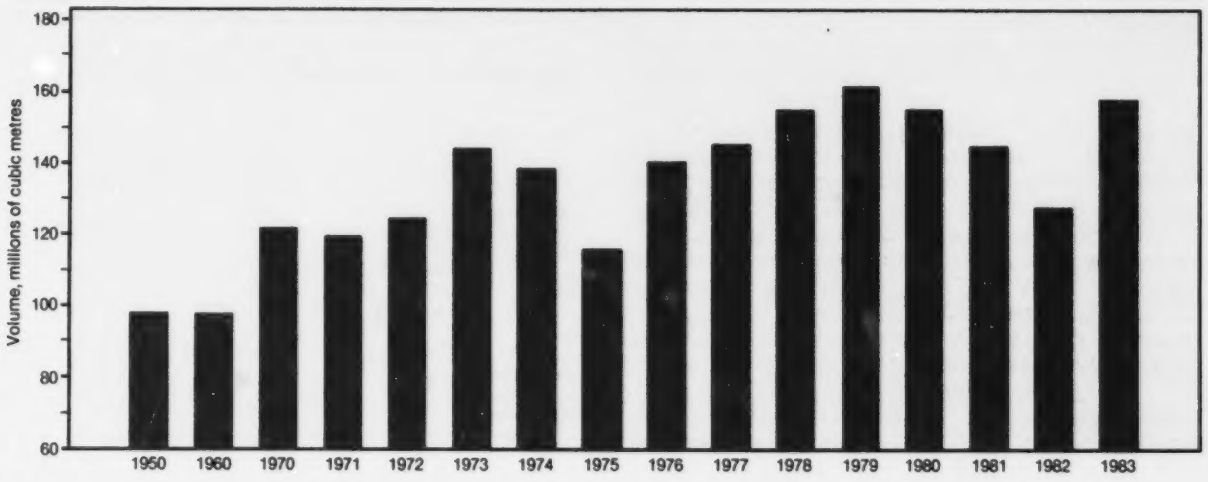
[1]Allowable cut is designated by the provinces on the basis of their forest inventories and refers to the volume of wood that may be harvested under management for a given period. Calculations of allowable cut are based on regeneration rates, growth conditions of the forest and other factors relevant to an assessment of forest renewability.
Source: Environment Canada, "A Forest Sector Strategy for Canada", Discussion paper on file (Ottawa: Canadian Forestry Service, 1983).

Table 4.11
Percentage of Area Burned by Forest Type

	Merchantable Timber				Regeneration & Immature				Cutovers & Others[1]			
Province or Territory	1978	1979	1980	Average 1970-79	1978	1979	1980	Average 1970-79	1978	1979	1980	Average 1970-79
British Columbia	52.8	48.0	14.7	21.1	18.5	14.7	35.2	21.2	28.7	37.3	50.1	57.7
Alberta	27.8	62.2	61.5	43.9	7.7	2.5	7.7	12.0	64.5	35.3	30.8	44.1
Saskatchewan	0.1	0.2	6.0	5.6	0.1	0.1	0.6	27.3	99.8	99.7	93.4	67.1
Manitoba	43.6	50.9	39.3	35.1	9.7	16.9	19.8	15.4	46.7	32.2	40.9	49.5
Ontario	1.3	25.0	39.8	20.9	4.8	10.1	19.2	28.4	93.9	64.9	41.0	50.7
Quebec	12.8	38.7	13.7	55.0	39.7	39.2	23.5	23.7	47.5	22.1	62.8	21.3
New Brunswick	19.4	18.2	17.4	33.3	12.8	9.2	57.8	22.1	67.8	72.6	24.8	44.6
Nova Scotia	28.3	24.4	51.9	45.5	3.8	3.8	1.5	7.1	67.9	71.8	46.6	47.4
Prince Edward Island		10.0										
Newfoundland	2.1	63.3	54.7	9.6	0.3	36.7	16.6	4.1	97.6		28.7	86.3
Yukon	5.7	0.6	34.1	29.1	16.3	0.0	51.2	5.9	78.0	99.4	14.7	65.0
Northwest Territories	0.2	1.1	0.6	5.1	0.6	1.8	0.5	24.2	99.2	97.1	98.9	70.7
Canada	14.4	8.5	20.4	14.8	7.4	2.7	7.7	22.3	78.2	88.8	71.9	62.9

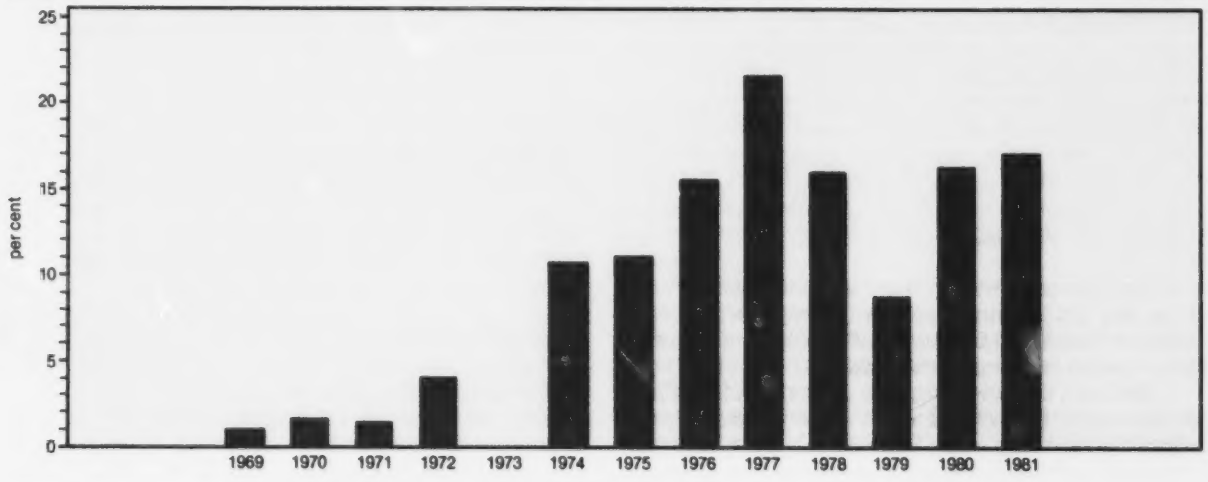
[1]Others include land classified as barren and scattered within the Boreal Shield and other ecozones. These areas generally contain shallow soils and bedrock and are insufficient to support merchantable timber. These areas are often dry and burn readily. Also included are non-merchantable forest areas in zones 1, 6, 8 and 10 where fires are generally allowed to burn freely.
Source: Environment Canada, *Canadian Forest Fire Statistics*, Part I — 1978, Part II — 1979, Information Report PI-X-9; *Canadian Forest Fire Statistics 1980*, Information Report PI-X-17 (Ottawa: Canadian Forestry Service, 1981, 1982).

Figure 4.9
Roundwood Production in Canada, 1950-1983



Source: Statistics Canada, *Logging*, Catalogue 25-201, 1984.

Figure 4.10
Full-tree Harvesting[1] as a Percentage of Total Canadian Roundwood Production



[1] Full-tree harvesting: whole trees, including branches and tops, are harvested.
Source: Canadian Pulp and Paper Association.

Table 4.13
Allowable Annual Cut and Harvest of Softwoods, 1979
(thousands of cubic metres)

Province or Territory	Allowable Cut[1] 1979	Harvest (Average 1979-1980)	Allowable Cut less Harvest
Newfoundland	2 940	2 594	346
Prince Edward Island	NA	150	NA
Nova Scotia	3 273	3 804	– 531
New Brunswick	6 790	7 577	– 787
Quebec	36 000	28 352	7 648
Ontario	26 720	17 529	9 191
Manitoba	6 076	1 715	4 361
Saskatchewan	3 500	3 230	270
Alberta	14 639	7 170	7 469
British Columbia[2]	73 483	75 199	– 1 716
Yukon	NA	125	NA
Northwest Territories	NA	54	NA
Canada	173 750	147 499	26 251

[1]Allowable cut is designated by the provinces on the basis of their forest inventories and refers to the volume of wood that may be harvested under management for a given period. Calculations of allowable cut are based on regeneration rates, growth conditions of the forest and other factors relevant to an assessment of forest renewability.

[2]No allowable cut is available for private lands in B.C. outside tree farm licences and for some of the remaining old temporary tenures. The combined harvest from these lands probably exceeds a sustainable allowable cut. In the case of provincial Crown lands, the harvest is approximately equivalent to the annual allowable cut. The estimate shown here includes 5 million cubic metres for private land.

Source: Environment Canada, "A Forest Sector Strategy for Canada", Discussion paper on file (Ottawa: Canadian Forestry Service, 1983).

Table 4.14
Site Preparation, Planting and Seeding as a Percentage of Average Harvest, 1975-1980

Province or Territory	Harvest[1] (thousands of hectares)	Site preparation[1] as % of area harvested	Planting and seeding as % of area harvested
British Columbia	177.8	39.6	34.1
Alberta	21.3	77.0	59.3
Saskatchewan	14.8	34.5	36.3
Manitoba	(18.9)[2]	(21.9)	(8.6)
Ontario	191.9	24.5	28.1
Quebec	195.5	3.8	*10.2
New Brunswick	(92.4)	(15.0)	(11.2)
Nova Scotia	29.6	4.7	7.5
Prince Edward Island	1.6	7.7	6.6
Newfoundland	(15.8)	(2.3)	(0.2)
Yukon	4.9	7.2	0.0
Northwest Territories	0.7	0.0	0.0
Canada	765.2	21.8	21.8

[1]Annual average 1975-1980.

[2]Numbers in parentheses are estimates.

Source: Environment Canada, Canadian Forestry Service, *Silviculture Statistics for Canada*, 1982.
Special tabulations, 1983, by Forestry Statistics and Systems Branch, based on *Canada's Forest Inventory, 1981*.

to 600 kilometres. Further, there is a softwood deficit in the Atlantic Maritime ecozone (mainly Nova Scotia and New Brunswick) that comes in the wake of already heavy losses to the spruce budworm.

Methods of harvesting also affect the character of the forest in perhaps more subtle ways. Most logging operations are increasingly mechanized (indicated by declining employment in the forest sector — down from 60 701 in 1965 to 48 402 in 1981). At the same time, the volume of timber removed has increased (Figure 4.9). Clearcutting is the prevailing harvesting technique, especially in the even-aged northern forest, and the method often employed in more fragile areas, such as the steep upper slopes of the mountains of British Columbia. The larger the area clearcut, the more likely the potential environmental effects from slides, erosion and so on. Unfortunately, there are no data on the average size of clearcuts.

There is a strong trend towards full-tree logging, a method under which trees are not delimbed and topped at the felling site but are skidded to a central location for processing. This method can deprive the forest of an important source of nutrients (largely contained in the foliage and branches). The trend is shown in Figure 4.10. Full-tree logging constituted 17 per cent of total Canadian roundwood production in 1981. In Quebec this method accounted for 35 per cent of the total harvest that year.

Planting and Silviculture

Efforts to enhance Canadian forests are turning increasingly to silviculture. Intensive silviculture, if done with care, may increase forest productivity considerably. At the same time, most silviculture programs reduce species diversity by replanting with a more selected, smaller species mix. This practice changes not only the dominant species of the forest ecosystem but also the forage opportunities for wildlife. Significant shifts in forest fauna are known to accompany change in forest cover (see Chapter 6).

Site Preparation and Planting

Areas of site preparation, planting and seeding, expressed as a percentage of area harvested, are given in Table 4.14. (Site preparation refers to activities such

Table 4.15
Age of Dominant and Co-dominant Trees in Abandoned Farmland of Central Prince Edward Island, 1981[1]

Age (Years)	Percentage of Total	Average Year of Origin
11-20		
21-30	5.5	1955
31-40	22.9	1946
41-50	34.9	1936
51-60	20.4	1926
61-70	9.9	1916
71-80	3.0	1906
81-90	2.5	1896
91 +	0.9	1886

[1]Based on 566 random samples, measured in 1981.
Source: Dendron Resource Surveys Ltd., Forest and biomass inventory, prepared for the Prince Edward Island Department of Agriculture and Forestry, 1982.

as ground break-up and burning and clearing of brush.) Site preparation and planting are highest in Alberta, where, of the total area harvested between 1975 and 1980, 77 per cent was site-prepared and 59.3 per cent was planted. In British Columbia and Saskatchewan, roughly one-third of the area harvested is site-prepared and planted. In Ontario, the corresponding figure is closer to one-quarter. There was comparatively little site preparation or planting in Quebec and the eastern provinces during this period.

Physical Restructuring

Forests are preserved, created and destroyed through shifting patterns of land use. Forests can be converted to farmland or vice versa (as in eastern regions in recent years). The creation of reserves and preserves offers varying degrees of protection to forestlands. The construction of hydro dams, with their flooding of lowlands, turns some forests into swamps or lakes. Cities and industrial areas expand at the expense of surrounding forests. Forested lands may be used for grazing, mining, or other purposes. Each of these processes has somewhat different effects, and each is prevalent in different regions (see Chapter 7).

Historically, one of the major influences on Canadian forests was the expansion of agriculture. Often, agriculture was possible only after massive land-clearing involving considerable deforestation. In the western regions (particularly in the Boreal Plain and sections of the Pacific Maritime ecozone), land-clearing continues. But most potential agricultural land is already in production, and shifts between agriculture and forestry now run in both directions. In the Atlantic Maritime and Mixed-Wood Plain ecozones and portions of the Boreal Shield, the problems of maintaining economically viable farming operations have led to the abandonment of farms and the reforestation of these lands.

Although hard data are lacking, it seems probable that reforestation of abandoned farmlands, especially in eastern and central Canada, may add to the total woodland in these areas. Almost half the agricultural land in the Atlantic Maritime, and one-quarter of the farmland in the Mixed-Wood Plain, have ceased to be cultivated in the last 50 years. The extent to which these lands have been reforested is not well documented.* A study of abandoned farms in Prince Edward Island illustrates the process by which forest stands take over old fields (Table 4.15).

In established farmlands, there is a continuing trend towards a decline in woodlots. The tendency is strongest in the prairie and Atlantic provinces, but it is also prevalent in all agricultural regions (Table 4.16). Farm woodlots as a percentage of total farmland declined from 13.1 per cent in 1951 to 5.4 per cent in 1981.**

In the rangelands of the Montane Cordillera, grazing practices conflict with forest management. The issue is a complex one. Soil erosion, soil compaction and damage to young growth are among the effects. In addition, heavy grazing reduces the amount of fuel for fires, inhibiting the regeneration of these fire-dependent forests.

Conversion of forest to urban use, while locally significant and often highly visible, involves statistically small areas on a national basis. For example, from 1966 to 1971 the total conversion of rural land to urban use was 86 000 hectares, of which approximately 22 per cent was formerly forest.[1] The increase in urban forest reserves or in parks is perhaps of greater significance.

Transportation and utility corridors and seismic lines form a dense network in some regions and account for significant deforestation. Seismic lines are particularly important consumers of forested lands in the Boreal Plain.

Forest roads, skidroads and landings associated with harvesting activity are also taking an indirect toll on the forest. The exposure of relatively sterile mineral soils during road, skidroad and landing construction, and soil compaction and puddling during yarding operations, place a stress on the forest by increasing soil erosion and reducing soil quality. Major effects have been observed on steep slopes. This is particularly important in the southern portion of the Montane

*Some of the abandoned farmland would presumably be woodlot.

**The high rate of decline in woodlots in central and eastern Canada may be more apparent than real, because farms that have been abandoned tended to have a higher proportion of their land in woodlots than those that have remained in farming. In western Canada, however, woodlot decline is likely to be due to land clearing.

Table 4.16
Area of Farm Woodlots by Province, 1951-1981
(thousands of hectares)

Province	1951	1961	1971	1976	1981
Newfoundland	15	8	5	8	6
Prince Edward Island	140	120	85	75	65
Nova Scotia	747	552	300	262	241
New Brunswick	827	498	276	227	201
Quebec	2 377	1 822	1 254	1 160	1 069
Ontario	1 559	1 318	931	833	742
Manitoba	734	603	389	376	248
Saskatchewan	1 192	888	404	415	282
Alberta	1 160	866	674	709	493
British Columbia	468	305	342	302	204
Total	9 219	6 980	4 660	4 367	3 551
Total area of farms[1]	70 434	69 829	68 662	68 427	65 889
Percentage	13.1	10.0	6.8	6.4	5.4

[1]A 1981 census farm is defined as a farm, ranch, or other agricultural holding with sales of agricultural products during the past 12 months of $250 or more.
Source: Environment Canada, *Selected Forestry Statistics-Canada*, Information Report E-X-32 (Ottawa: Canadian Forestry Service, 1984).

Cordillera where over one-third of the harvesting is on a gradient greater than 51 per cent.

Haul roads may be completely lost to future forest production. In some cases, trees established on skidroad surfaces have shown enhanced growth (compared to non-road sites), but more often they show reduced growth in the order of 30 to 50 per cent, especially when the soil is alkaline, coarse-textured and/or strongly podzolized, and in cool, wet areas.[3]

Pollution

The effects of air pollution on Canadian forests have been observed in sites downwind from smelter operations or other industrial processes that release large volumes of sulphur dioxide and other pollutants. Typically, the damage zone reflects the shape of the plume from the stack. In certain cases, only bare soil and rock remain in the centre of the pollution zone, and dead and dying trees may occur as far as 25 kilometres downwind from the source. These local 'hot spots' may be a thing of the past, as intense sources of industrial emissions are now subject to regulatory control through the construction of high stacks or the installation of pollution abatement equipment.*

A more insidious threat from air pollution may be the increase in acid precipitation. The main sources of emissions leading to the formation of acid precipitation are thermal power plants, smelters and motor vehicles. The pattern of dispersal of the acid precipitation means that the highest concentrations are found in the Mixed-Wood Plain, the Atlantic Maritime and the eastern part of the Boreal Shield (Figure 4.11). Allowing for the varying ability of soils to neutralize acidity, the areas at highest risk are in portions of the Boreal Shield and Atlantic Maritime ecozones.

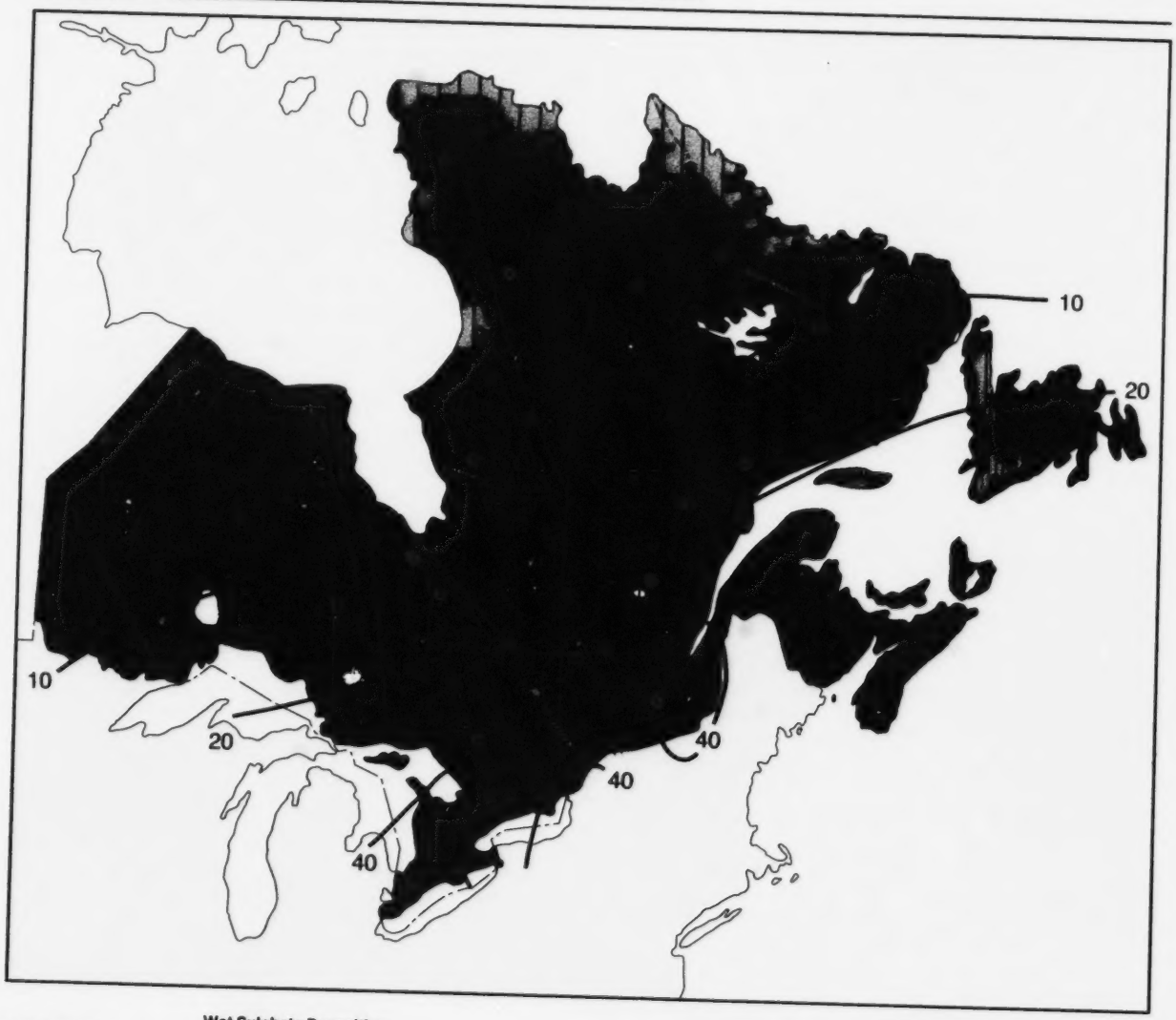
The effect of acid rain on forests is still relatively little understood, but it is the cause of recent widespread concern. Laboratory experiments have proved that increased acidity reduces plant growth rates. It is also known that acidity, by cation exchange, releases toxic materials such as aluminum that may affect plant growth. Some lichens are highly susceptible to acidity and disappear from affected areas. Acid rain and other forms of air pollution have been implicated in the dieback of the central European forests.

Climate

Extreme climate-induced stress, even in the short run, has important effects on forests. The Montane Cordillera provides good examples. A large blow-down near Prince George provided breeding grounds for a spruce beetle and led eventually to serious infestation. Along the eastern edge of the montane zone, unusually warm periods early in spring often kill conifers, as warmth and sunlight increase transpiration while the

*High stacks in effect convert an intense local problem to a long-range problem (i.e., acid rain).

Figure 4.11
Wet Sulphate Deposition[1] and Soil Sensitivity[2] in Eastern Canada



[1] Wet sulphate deposition is the weight of sulphate in rain and snow. Currently, this measure is considered to be the best indicator of acidic deposition.
[2] Sensitivity to changes in forest cation nutrient status.
Source: United States-Canada Memorandum of Intent on Transboundary Air Pollution, Impact Assessment Working Group, *Interim Working Paper*, October 1982; *Final Report*, January 1983.

still frozen ground cannot supply the required water. This results in the drying out of the forest canopy, producing a characteristic reddening of the crowns — hence the term 'redbelt'. This phenomenon tends to be concentrated in belts along sensitive temperature/moisture isoclines.

ASSESSMENT

There is no question that the character of the Canadian forest has changed drastically since the time of European settlement. Much of the virgin forests of the Pacific Maritime has disappeared, and only remnants remain of the once majestic rain forests. In the Boreal Plain, the aspen parkland and its associated large and small mammal component have all but been eliminated by land conversion to agricultural use. In the east, white pine, which dominated much of the Ottawa Valley and other reaches of the Boreal Shield, is vastly reduced. In their stead, many so-called trash species (those of inferior quality for human use) have sprung up. Poplar and birch are prominent among these early successional species.

The species composition of the forest is continuing to undergo transformation under a variety of influences — selective cutting, silvicultural practice, disease, fire and climate change all play a role. Diseases and harvesting may be particularly important in accounting for depletion of eastern softwoods, particularly in areas of the Boreal Shield and Atlantic Maritime ecozone.

Sizable areas of once forested land appear not to be properly regenerated after harvesting and other stresses (Table 4.4). Unfortunately, the criteria for not sufficiently restocked forestland are not uniform across Canada; thus, accurate regional comparisons cannot be made at present.

With respect to forest insect pests, there appears to be a disquieting tendency towards increased incidence. Epidemics of budworm and pine beetle are a natural component of Canadian forest ecosystem dynamics. However, the recent budworm infestation is the most severe of the century, perhaps because although pesticides save trees, they also protect the food supply upon which the budworm thrives. Further, some weakening of forest trees through the secondary effects of air pollution may facilitate the spread of insects and diseases. For the moment, these suggestions remain highly speculative.

Further research is required to ascertain quantitatively the degree to which human activities have contributed to current conditions and trends in Canadian forest ecosystems. For example, fire, harvesting, and insect pest outbreaks affect the age distribution of the forests in varying degrees. Although there appears to be a marked transition towards younger age classes, it is difficult to determine the extent to which the current pattern deviates from that of the natural forest, or from the desirable state of managed forests in different parts of the country. With appropriate research these data gaps can be filled.

There is growing concern, especially in light of the current European experience, about the threat of acid precipitation to the health of forest ecosystems. Acid rain and heavy metal toxicity are suspected of causing damage to forests in Canada, but conclusive data are lacking. Sensitive zones in eastern Canada have been identified, and forest growth and regeneration patterns in those regions bear careful watching.

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INTRODUCTION

Aquatic ecosystems are dynamic, living organizations that are exceedingly complex. Scientific understanding of factors that regulate ecological composition and structure, even in a simple Arctic pond, is far from complete. Influences act with varying intensities and often on different time scales. Collectively, they affect the response of an ecosystem. In the face of this complexity, it is necessary to select indicators that will allow the observer to track changes or perturbations in the ecosystem that are brought about by the activity of human societies or by nature itself. Biological indicators commonly used to assess the effects of human activity are primary productivity, biotic composition, the response of organisms to contaminants, disease incidence and the presence of exotic species. The dominant short-term influences on aquatic ecosystems are harvesting, physical modification of habitat (e.g., wetland conversion), nutrient loadings, toxic contamination and the introduction of exotic species. Over the long term, climatic changes or the incidence of such natural phenomena as red tides (from the organism *Gonyaulax* which releases a toxin causing paralytic shellfish poisoning) play a role (see Table 5.1 and Figure 5.1).

Ideally, indicator data would be gathered on an ecological basis. For a good many indicators, however, data are insufficient or not collected in a comprehensive way. In this chapter, we use data gathered for special purposes (e.g., commercial fishery statistics) as surrogates for some indicators. Changes in catch may in some cases provide information about changes in fish stocks when adjusted for technological, economic and social factors. Such data do not substitute for analytical assessment of the status of fish stocks. Other data have been selected from specific studies and usually address limited geographic areas or particular issues. Because indicators are at best a selection from among many components, it is often not possible (nor is it intended) to determine their full ecological significance. Thus there is no claim to a comprehensive analysis. The reader should also resist the temptation to look for cause and effect relationships.

This chapter selects aspects of Canada's major aquatic ecosystems. It is divided into four sections: the Great Lakes and other freshwater systems, the Atlantic marine ecosystem, the Pacific marine ecosystem, and the northern marine ecosystem.

For each section, the discussion is organized as follows. An introduction provides background material about the particular aquatic system and identifies the main topics to be discussed. This is followed by a description of the ecosystem in terms of a group of indicators. Then follows a description of major presumptive influences on the ecosystem. The concluding section attempts a general environmental assessment that relates the state of the ecosystem to the various influences. This last section is descriptive.

Table 5.1
Major Influences on Canadian Aquatic Ecosystems

		Physical Restructuring			Pollution			
Ecosystem	Harvesting	Wetland Loss	Sediment Loading	Dams & Diversions	Sewage[1]	Contaminants[1]	Introduction of Exotics	Climate Change[3]
Inland Waters[2]	■	■	■	■	■	■	■	■
Atlantic Marine	■	■		■	■	■		■
Northern Marine	■			■		■		■
Pacific Marine	■	■	■	■	■	■		■

■ Strong influence

[1] Sewage and contaminants in Atlantic and Pacific waters are largely contained to estuaries, harbours and coastal areas near human settlements.
[2] Includes Great Lakes.
[3] Climate change occurs on a longer time scale than any of the human influences.
Source: Working Group from Department of Fisheries and Oceans and consultants to the State of the Environment project.

Figure 5.1
Schematic Representation of Stresses and Responses in Aquatic Ecosystems

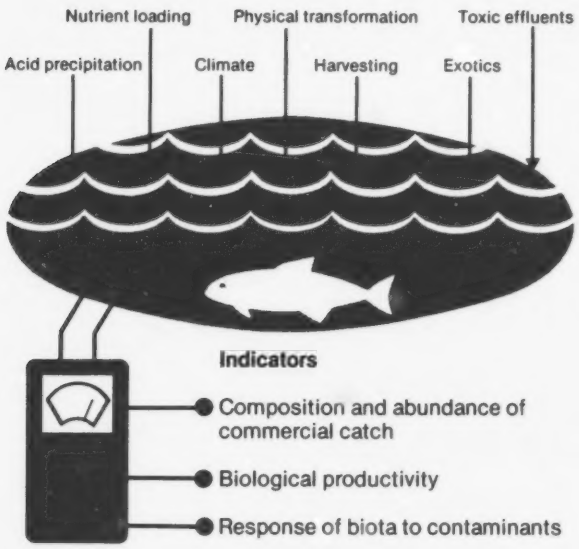
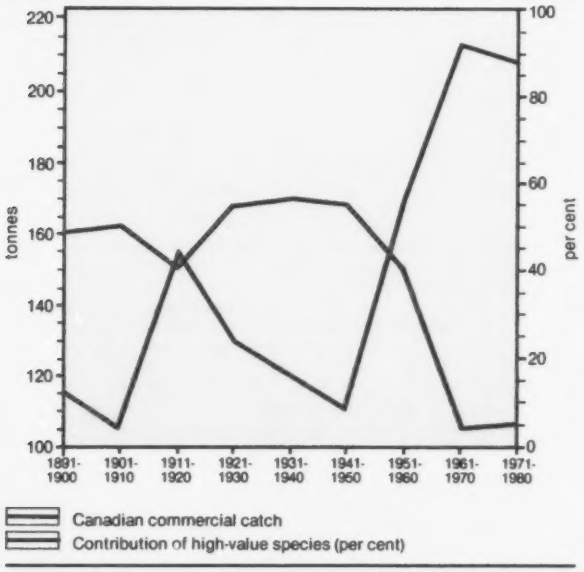


Figure 5.2
Contribution of High-value Species to the Canadian Commercial Catch in the Great Lakes Fishery, 1891-1980



Source: International Joint Commission, Great Lakes Water Quality Board, Report on Great Lakes Water Quality, 1981.

THE GREAT LAKES AND OTHER FRESHWATER ECOSYSTEMS

INTRODUCTION

Canadians depend on fresh water for drinking water, commercial and sports fisheries, and industrial and recreational use. Water pollution has caused much concern in recent years. The public has heard that Lake Erie is dead or dying and that the aquatic environment in many regions of the country has deteriorated. As shown in the following section, the Great Lakes show most of the symptoms of a stressed ecosystem: increased abundance of short-lived exotic species and loss of the more desirable native species, accelerated eutrophication (raised nutrient levels), declines in the average size of surviving biota, and significant levels of contaminants in sediments and biota.

We go on to describe major influences on the state of aquatic ecosystems. These include commercial harvesting; physical restructuring of the environment (particularly through the loss of wetlands, sediment loadings and physical obstructions); nutrient loadings; introduction of non-native species; and climate change.* In a final section the changes in freshwater ecosystems are related in very broad terms to these major influences.

STATE OF THE GREAT LAKES AND OTHER FRESHWATER ECOSYSTEMS

Biotic Composition

The composition of the Canadian commercial catch in the Great Lakes fishery over the period 1891-1980 is given in Figure 5.2.** While the volume of landed catch doubled over the period, the contribution of preferred high market value species (blue pike, lake trout, whitefish, sauger and walleye) fell from 50 per cent to approximately 3 per cent.†

This precipitous proportional decline was offset by smelt fishing in Lake Erie which accounts for a large part of the increase in tonnage. These changes occurred principally from the 1940s onward. Table 5.2

*Often significant changes in the state of inland waters can occur from a single project, e.g., the construction of the Bennett Dam in British Columbia. In other instances, a number of activities together may transform a system, e.g., Dauphin Lake, Manitoba.

**Throughout this discussion, references to changes in abundance of fish stocks are based on inferences from data on commercial (and sports) catch. The shift in commercial catch from desirable to less desirable species, in this case, gives a reliable indication of changes in the composition of stocks. A scientific survey of fish stocks showed clearly that Lake Ontario stocks are now dominated by small, pelagic fishes, many of which are non-native (see Table 5.6).

†This comparison in terms of percentage contribution to total catch may distort the picture somewhat in cases where new markets have developed for the low-valued species, thus entailing an expansion of effort to fish these stocks and, as a result, a more precipitous decline in the share of highly valued stocks. In the 1970s, some highly valued stocks did not appear in the commercial catch because of bans on contaminated fish.

summarizes changes in total landings by lake of the 10 most valued species from 1956 to 1982. These summary data suggest a modest recovery in the commercial catch of valued species since the mid-1970s.

Lake Ontario's recovery stems from increased yields of yellow perch and American eel, beginning in the mid-1960s. In the most important of all Great Lakes fisheries, that of Lake Erie, recovery has been under way since the late 1970s, with a re-opening of the walleye fishery and a rebound of yellow perch. The main basin of Lake Huron has shown signs of recovery since the late 1970s, led by rebounds in yellow perch and lake whitefish (the latter results from effective sea lamprey control measures) with smaller contributions from walleye and deepwater cisco. In Lake Superior, recovery has been under way since the early 1970s, with increased landings of yellow perch, lake trout, deepwater cisco and lake whitefish.[6] These reversals may be early signs of rehabilitation of the Great Lakes fish communities. Further analysis is required to confirm this.

The majority of the lower Great Lakes fish community, however, still consists of small, surface-dwelling (pelagic) fishes, many of them accidentally or intentionally introduced to these waters (Table 5.3).

Table 5.2
Commercial Fish Landings of High-value Species[1] in the Great Lakes, 1956-1982
(thousands of tonnes)

	Lake Ontario	Lake Erie	Lake Huron (Main Lake)	Lake Superior
1956	398	13 721	506	499
1960	303	5 453	1 426	256
1965	346	8 615	867	280
1970	541	9 103	422	180
1975	446	3 791	611	455
1980	497	6 552	1 033	618
1982	588	5 079	1 172	437

[1]High-value species based on market value per unit weight include lake sturgeon, yellow walleye, splake, American eel, coho salmon, yellow perch, lake trout, deepwater cisco, lake whitefish and crappie.
Source: Ontario Ministry of Natural Resources, *Ontario Commercial Fish Industry Statistics on Landings, 1956-1982*, (Toronto: various years).

Table 5.3
Appearance and Conspicuous Increase of Exotic Species[1] in the Great Lakes

Species	Lake, Date of First Appearance and (Increase)	Lake, Date of Final Appearance and (Increase)	Current Distribution
Sea Lamprey[2]	Ontario, 1835 (1920s)	Superior, 1946 (1950s)	All[4]
Alewife	Ontario, 1873 (1873)	Superior, 1953	All except St. Clair
Pink Salmon	Superior, 1956 (1969)	Ontario, 1979	All
Coho Salmon	Superior, 1966 (1969)	Erie, 1979	All except St. Clair
Kokanee Salmon	Huron, 1964 (1967)		Huron
Chinook Salmon	Superior, 1967 (1971)	Ontario, 1970 (1971)	All except Erie, St. Clair
Rainbow Trout	St. Clair, 1882 (1928)	Ontario, 1922 (1947)	All
Atlantic Salmon[3]	Ontario/Erie, 1970s		Erie
Brown Trout	Erie/St. Clair, 1913	Superior, 1930	All
Rainbow Smelt	Huron, 1925 (1930s)	Erie, 1935 (1940s)	All
Splake	Huron, 1954 (1980s)		Huron
Goldfish	All Lakes, 1880s (1944-1960)	—	All
Carp	St. Clair, 1883 (1900)	Superior, 1915 (1956)	All
American Eel	Ontario, natural	Erie, 1976	Ontario, Erie
White Perch	Ontario, 1952 (1957)	Erie, 1950s	Ontario, Erie

[1]Refers to Canadian occurrences, except where U.S. occurrences are suggestive of Canadian status. Other introductions have occurred, but populations have not been sustained.
[2]Perhaps natural to Lake Ontario.
[3]Reintroduction.
[4]All Great Lakes. Because of the nature of migrations, Lake St. Clair is considered part of the Great Lakes system.

Table 5.4
Exotic Species of Fish Flourishing in Lake Erie, 1984

Species	Desirability to Fishermen	Time of Appearance	Cause of Appearance	Recent Status[1]
Carp	Moderate	1881	Deliberate introduction	Abundant in shallow waters
Goldfish	Low	circa 1900	Liberation by aquarists	Common, esp. in Western Basin
Sea Lamprey[2]	None	1921	Invasion likely via Erie and/or Welland Canals	Common, esp. in Eastern Basin
Rainbow Trout	High	1921	Deliberate introduction	Common, esp. in Eastern Basin
Alewife	Low	1931	Invasion from Lake Ontario where introduced accidentally	Common to abundant
Rainbow Smelt	High	1932	Invasion after deliberate introduction in Lake Michigan watershed	Very abundant, esp. in Central and Eastern Basins
White Perch	Moderate	early 1970s	Invasion from Hudson River via Erie Canal and/or Lake Ontario and Welland Canal	Common, esp. in Western Basin

[1]Based on qualitative assessment of abundance. Relative ranking based on sequence: absent, scarce, common, abundant.
[2]Perhaps not exactly flourishing in view of the concerted and partially successful effort to control them, but still rather common, especially in the Eastern Basin.
Source: Personal Communication, H.A. Regier, University of Toronto, 1984.

These invaders are generally less valued by commercial fishermen (Table 5.4). Lake Erie provides the best example and one for which there are data available. Of the invaders that now flourish in Lake Erie (carp, goldfish, sea lamprey, alewife, white perch, rainbow smelt and rainbow trout), only the latter two are valued by fishermen.

A number of exotic species are now common in the inland fisheries of western Canada (Table 5.5). The majority of the new species have been introduced deliberately, primarily for sport fishing, but some species have invaded via transboundary waterways. Rainbow trout and brook trout are commonly stocked and have established reproducing populations throughout the western provinces. Carp were introduced into North America in the 1830s and have now spread throughout most of the continent, including British Columbia, Saskatchewan and Manitoba. They are now fished commercially in Manitoba and Saskatchewan.

Table 5.6 classifies the fish stock into three categories: small pelagic fish, large pelagic fish and benthic fish. In both Lake Erie and Lake Ontario, the small pelagic fish have increased in abundance relative to benthic fish and large pelagics. Changes in the composition of the fish community have accelerated since 1951.

The fishery of upper Lake Champlain and the Richelieu River basin provides an example of changes in biotic composition in a smaller managed system. This watershed supported a salmon fishery in the 1800s, but this was lost as access to tributary spawning sites along the lake became restricted. The states of New York and Vermont and the province of Quebec are attempting to rejuvenate the cold water fishery of the Lake by stocking it with landlocked salmon, steelhead and lake trout. The system now supports about 80 species of fish, 14 of which are considered major game fish varieties. Several undesirable exotic species, such as lamprey and gar, also flourish in Lake Champlain. Species of importance include walleye, smallmouth bass and yellow perch, the latter contributing about 97 per cent to the winter catch in Missisquoi Bay. About 8 per cent of Canada's total American eel catch is taken from Missisquoi Bay and the Richelieu River. Other species such as lake whitefish and carp are also taken commercially, and increased sport fishing locally has resulted in a commercial bait fishery for golden shiners and eastern silvery minnows.

Before 1940, fisheries in the prairies were characterized by increased catches of all species, the opening of fisheries in more remote areas, improved market access, and a decline in competition from the Great Lakes fishery. Since the 1950s overall catches have remained stable, but there has been a shift from southern to northern lakes. Prior to 1940, over 90 per cent of Manitoba's catch came from the south. There has also been a shift in species composition; walleye landings have decreased, while pike and sucker landings have increased (Table 5.7).

These general changes are illustrated by examining some lakes in greater detail. Walleye (*Stizostedion vitreum*) is the most valuable commercial and recreational fish species in western Canada. Stocks are subject to intensive fishing pressure, as well as environmental variations and man-made disturbances. These pressures have resulted in a decline in stocks of walleye. On Lakes Winnipeg, Winnipegosis and Manitoba, the production of walleye has fallen to 1.8 million kilograms, less than 40 per cent of historical levels. An approximate measure of the economic loss from these three lakes is close to $5 million annually. In Dauphin Lake (once the most productive walleye lake in Manitoba), the commercial harvest declined

Table 5.5
Exotic Fishes in Western Canada

Species	Origin and History
Rainbow trout (*Salmo gairdneri*)	Native to British Columbia and a small part of northwestern Alberta. Commonly stocked and established in all four provinces and periodically stocked in restricted areas of Northwest Territories and Yukon. First stocked in Saskatchewan in 1924 and in Manitoba in 1938.
Brown trout (*Salmo trutta*)	Native to Europe. First introduced to Saskatchewan and Alberta in 1924, British Columbia in 1932 and Manitoba in 1943. Small established populations in the three former provinces but no longer widely stocked.
Brook trout (*Salvelinus fontinalis*)	Native to Hudson Bay coastline of Manitoba; naturalized and widely stocked populations in all western provinces. First introduced in British Columbia in 1908, Saskatchewan and Alberta in the 1920s and '30s and Manitoba in 1942.
Other salmonids	Kokanee (*Oncorhynchus nerka*) are native to British Columbia interior lakes and have been introduced in restricted areas of the prairie provinces. Coho salmon (*Oncorhynchus kisutch*) have been introduced into one area of Alberta. The hybrid splake (*Salvelinus namaychush* × *S. fontinalis*) is commonly stocked in the prairies.
Smallmouth bass (*Micropterus dolomieui*)	Originally restricted to the fresh waters of eastern central North America; as a result of invasion and introductions, now found in Manitoba north to the south end of Lake Manitoba, central Saskatchewan and in lakes of the Columbia River system, and on Vancouver Island in British Columbia.
Largemouth bass (*Micropterus salmoides*)	Originally restricted to the fresh waters of eastern central North America, including the Great Lakes, it has now spread to southeastern Manitoba and to several lakes of the Columbia River system in southeastern B.C.
Other centarchids	A number of other members of the bass family (sunfish, crappies, etc.) have been introduced into states immediately south of the western provinces. Invasions through the Red, Missouri and Columbia River systems are probable.
Common carp (*Cyprinus carpio*)	Native to Europe and Asia; first introduced to North America in 1831 and to Canada in 1880. Through introductions and invasions, widespread in British Columbia, Manitoba and Saskatchewan, but has not reached Alberta or Yukon and Northwest Territories. First appeared in British Columbia as a result of invasions of carp established in the Columbia River system in the 1880s. First appearing in the Red River in Manitoba in 1938, they have spread throughout the Nelson River drainage system and were first recorded in Saskatchewan in the Assiniboine River in 1953.
Other species	There have been periodic introductions, some accidental, some intentional, of a number of species, but they have either not survived or are found only in very restricted areas.

Table 5.6
Changes in Species Composition of Lower Great Lakes Commercial Catch

	Lake Erie Ratios		Lake Ontario Ratios	
	Small Pelagics[1] to Benthics[2]	Small Pelagics to Large Pelagics[3]	Small Pelagics to Benthics	Small Pelagics to Large Pelagics
1901	0.3	0.1	0.4	0.2
1911	0.3	0.1	0.1	0.2
1921	0.2	0.1	0.1	0.1
1931	1.2	0.6	0.1	0.1
1941	0.4	0.6	0.1	0.1
1951	0.4	0.5	0.3	0.6
1961	4.4	2.7	0.4	7.9
1971	7.3	15.4	16.9	35.4
1981	12.5	9.4	18.1	113.2

[1]Small pelagics comprise smelt, alewife, yellow perch.
[2]Benthics (bottom feeders) comprise lake whitefish, burbot, sturgeon, northern pike, sauger, carp, walleye, channel catfish, lake trout.
[3]Large pelagics (open water fish) comprise blue pike, lake herring, white bass, sheepshead.
Source: Great Lakes Fisheries Commission, Technical Report No. 3 (Revised), September 1979, and unpublished data.

rapidly, from an average annual landing for the period 1946-1950 of 86.4 tonnes to 1.6 tonnes for the period 1961-1965. Between 1976 and 1980, the annual catch averaged 3.1 tonnes.[4]

Table 5.8 gives goldeye production from three large Manitoba lakes. Despite continuing demand for goldeye, catches of this species have declined dramatically, and it is now an insignificant part of the commercial harvest. The changes in species composition within lakes have also been dramatic. Dauphin Lake provides a good example. The major changes are listed in Table 5.9.

Changes in the composition of aquatic organisms other than fish are documented in special studies.[1] These studies can be used to assess the current state of water quality and determine the dynamic behaviour of aquatic ecosystems in relation to stress factors introduced by human beings. They include studies of the spatial distribution, density and growth rates of water weeds (macrophytes), small floating plant and animal life (plankton), and life forms on or in bottom sediments (benthic organisms).

One example is the change in abundance and composition of the burrowing mayflies of Lake Winnipeg. These benthic invertebrates serve as a major food source for fish. A comparison of surveys on the abundance and distribution of two species of mayflies (*Hexagenia limbata* and *H. rigida*) shows dramatic changes, especially in the south basin of Lake Winnipeg. In 1929-1930, the production of *Hexagenia* was

Table 5.7
Commercial Fish Production by Species in the Prairie Provinces, 1901-1980
(thousands of kilograms per year)

	Whitefish	Walleye	Pike	Suckers	Total[1]
1901-05	5 139	3 112	2 038	—	15 810
1906-10	2 869	2 440	1 930	—	11 645
1911-15	3 963	1 914	1 874	—	12 920
1916-20	5 552	2 225	2 121	957	15 214
1921-25	4 764	2 752	1 478	475	12 235
1926-30	5 584	4 609	2 360	775	19 316
1931-35	4 272	3 490	1 129	338	12 659
1936-40	4 544	4 600	1 790	838	19 898
1941-45	5 519	4 987	2 088	1 529	23 561
1946-50	4 633	4 962	2 228	1 171	21 068
1951-55	6 113	5 385	2 375	1 069	22 924
1956-60	7 861	4 031	2 874	2 220	25 324
1961-65	6 115	4 080	3 100	3 012	25 608
1966-70	6 186	2 649	3 170	2 140	22 153
1971-75	5 715	2 701	2 911	2 430	16 880
1976-80	6 268	3 952	3 489	2 221	19 653

[1]Includes all other species.
Source: Personal Communication, G.B. Ayles, Department of Fisheries and Oceans, Fisheries Research Branch, Western Region. Freshwater Institute, Winnipeg, 1984.

Table 5.8
Commercial Production of Goldeye from Three Manitoba Lakes, 1911-1980
(thousands of kilograms per year)

	Dauphin Lake	Lake Winnipegosis	Lake Winnipeg
1911-15	—	—	236.8
1915-20	—	16.8	187.8
1921-25	9.4	48.6	122.2
1926-30	15.5	55.9	249.5
1931-35	5.9	33.0	55.4
1936-40	10.8	43.7	67.7
1941-45	1.1	69.5	22.6
1946-50	0.1	44.1	1.4
1951-55	—	9.1	3.0
1956-60	—	5.9	8.3
1961-65	—	2.4	1.4
1966-70	—	9.5	5.0
1971-75	—	4.9	1.7
1976-80	—	3.5	4.7

Source: Personal Communication, G.B. Ayles, Department of Fisheries and Oceans, Fisheries Research Branch, Western Region. Freshwater Institute, Winnipeg, 1984.

estimated at 39 000 tonnes, while the survey of 1969 indicated a production of 28 300 tonnes — a 27-per cent decrease. For the lake as a whole, the ratio of *H. limbata* to *H. rigida* was 7:1 in 1930, while the survey of 1969 found that the ratio had declined to 4:1. *Trichoptera* or caddisfly populations also changed significantly.[2] Two species, *Molanna flavicornis* and *Phryganea cinerea*, have disappeared completely from the south basin of the lake and appear to be more restricted in density and distribution in the north basin. In contrast, species of *Oecetis* larvae were not found anywhere in the lake in the 1927-1932 survey, but in 1969 *Oecetis inconspicua* was widespread and occurred in densities of up to 180 per square metre in the south basin. Concurrently, there has been an increase in oligochaetes in the south basin.

Another study, although in U.S. waters (Saginaw Bay, Lake Huron), illustrates the response of phytoplankton to changes in nutrient conditions.[12] When the ratio of nitrogen to phosphorus declined, the response was a dramatic shift in the composition of the phytoplankton community over a six-year period, during which the dominance of blue-green algae was reduced and the proportion of diatoms increased (Figure 5.3). In this case, blue-green algae blooms and decomposition are symptomatic of cultural eutrophication.

Studies of plant communities in Lake Erie and Lake Ontario suggest that significant changes have occurred since the turn of the century. A rapid decline in rooted aquatic plants was followed by an increase in the dominance of phytoplankton and the nuisance algae *Cladophora*. Its presence in dense mats, coating rock and boulders near shore, renders the shoreline much less attractive for recreational purposes.

Biotic Size

The average size of individual fish in the landed catch has declined gradually over the past century, at least in the lower Great Lakes. This change reflects both a decrease in relative abundance (or in some instances extinction) of some larger species, and a decline in the average size of individuals within a species. In Lake Ontario the average weight of individuals (used as a proxy for size) in the landed catch is well below 0.5 kilograms. In contrast, in 1800 Lake Ontario was dominated by the larger individuals of relatively large species, often exceeding five kilograms (sturgeon, lake trout, lake whitefish, northern pike, muskellunge, walleye).[5]

Table 5.9
Species Composition of the Commercial Harvest of Dauphin Lake

	Goldeye & Walleye		Pikes & Suckers	
	Percentage of Total Harvest	Annual Mean Tonnes	Percentage of Total Harvest	Annual Mean Tonnes
1921-35	55	75	15	20
1966-80	6	3	88	42

Source: J.F. Flannagan, J.A. Mathias and W.G. Franzin, 1983.

Table 5.10
Lake Erie Mean for Chlorophyll a Concentration, Adjusted for Seasonal Cycle
(micrograms per litre)

	Western Basin	Central Basin	Eastern Basin
1968	8.27	5.045	5.378
1970	10.01	6.345	5.233
1972	11.81	—	3.675
1979	—	4.327	—
1980	—	3.045	2.850

Source: Environment Canada, *Statistical Assessment of the Great Lakes Surveillance Program, 1966-1981*, edited by A.H. El-Shaarawi, Lake Erie Scientific Series No. 136 (Burlington, Ontario: National Water Resources Institute/Canadian Centre for Inland Waters, 1984).

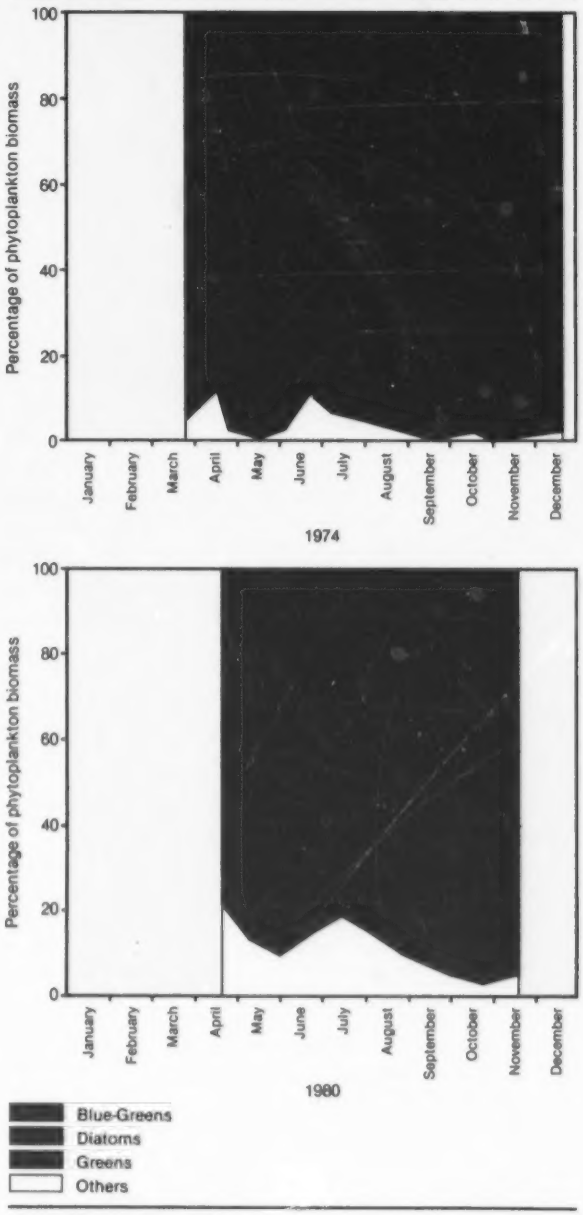
Primary Productivity

Historically, the offshore deeper waters of the Great Lakes were oligotrophic — that is, low in nutrients and in primary productivity (e.g., phytoplankton production). The quality of the deeper waters of Lake Erie and Lake Ontario 150 years ago was like that of the offshore waters of the upper lakes today. Figure 5.4 shows that the offshore surface waters of the lower lakes, compared to the upper lakes, have high levels of chlorophyll a, an index of primary productivity.

The change in chlorophyll a concentrations within a lake is generally difficult to interpret because significant seasonal variations obscure more general trends. Overall changes in concentrations, corrected for seasonal variation, are shown in Table 5.10. The data show that mean concentrations of chlorophyll a have declined in the central and eastern basins of Lake Erie over the 1970-1980 period.

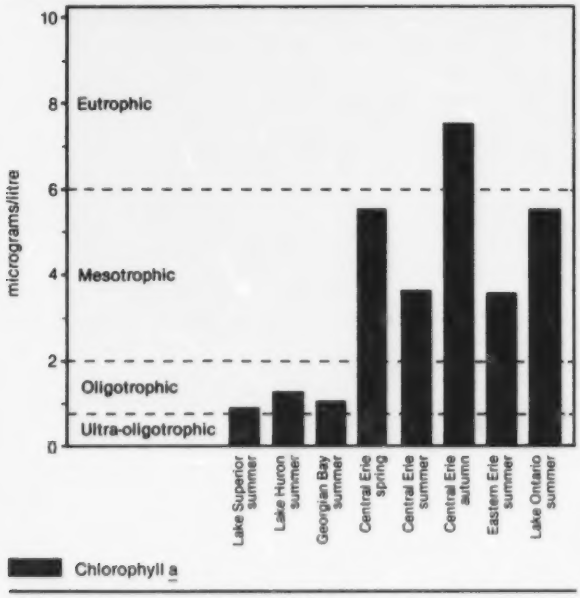
Concerted efforts by Canada and the United States to reduce phosphorus loadings, the main cause of eutrophication, have resulted in the decline of primary production, at least locally. Figure 5.5 shows a significant reduction in algal concentrations sampled in the Bay of Quinte after phosphorus controls were put in place.

Figure 5.3
Comparison of Phytoplankton Crop Composition over time in Segment 2 of Saginaw Bay



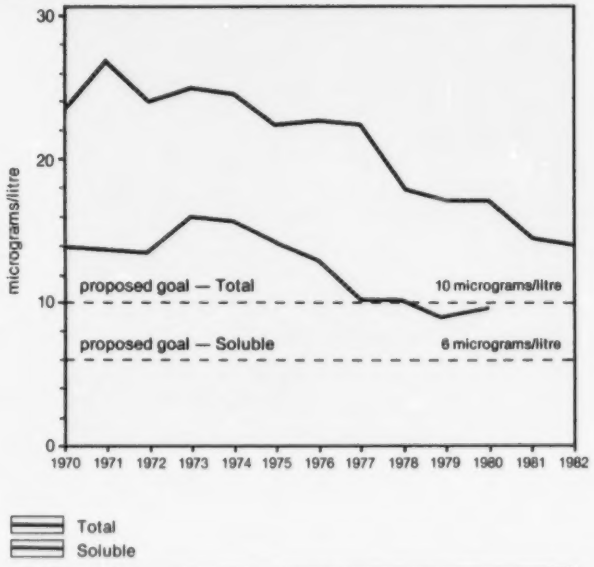
Source: Stoermer et al., 1982.

Figure 5.4
Total Chlorophyll a in Offshore Surface Waters of the Great Lakes, 1981



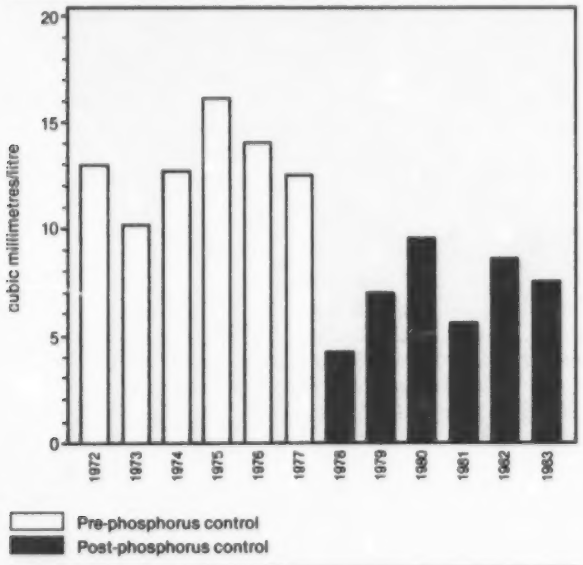
Source: H. Dobson, "Trophic conditions and trends in the Laurentian Great Lakes", *Water Quality Bulletin* 6/4 (1981): 146-151.

Figure 5.6
Spring Total and Soluble Phosphorus Concentrations in Lake Ontario, 1970-1982



Source: M. Neilson, "Report on Status of Open Waters of Lake Ontario" (Burlington, Ont.: Environment Canada, Inland Waters Directorate, 1983).

Figure 5.5
Concentration of Phytoplankton in Bay of Quinte, Before and After Phosphorus Control, 1972-1983



Source: Nicholls et al., 1985.

Nutrient Concentration

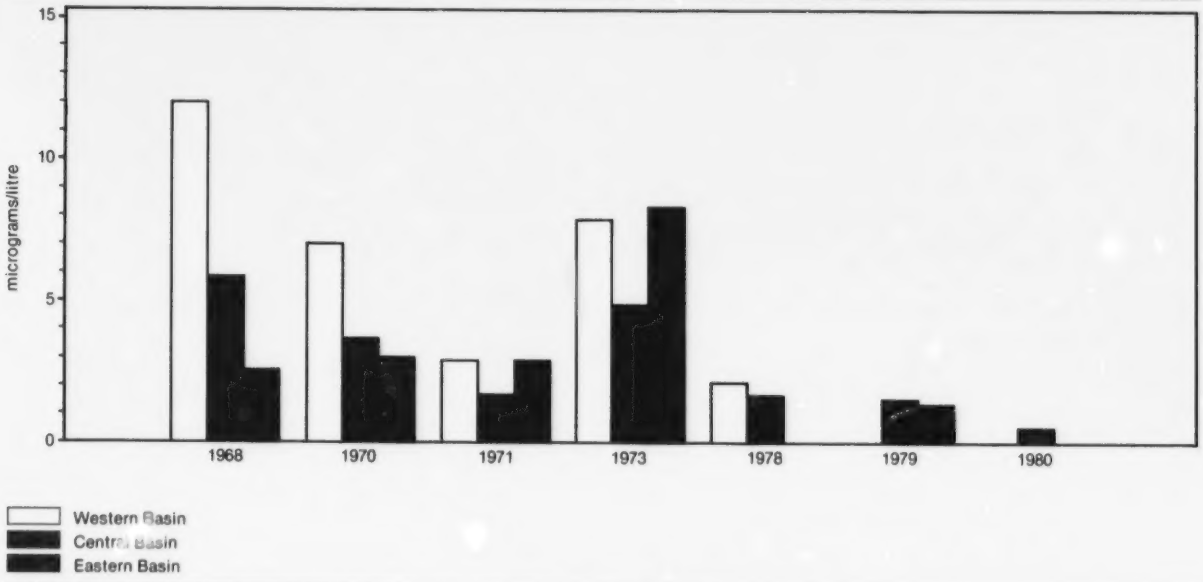
Loading of nutrients, leading to enrichment of the lower Great Lakes and local areas of the upper lakes, is widely considered to be a major problem. This situation was one of the primary concerns leading to the Canada-U.S. Water Quality Agreements.

As all phosphorus is not biologically available, soluble reactive phosphorus concentrations serve as the best indicator of available phosphorus in these waters. Figures 5.6 to 5.9 give the trends in soluble and total phosphorus concentrations in offshore waters for Lakes Ontario, Erie and Huron. These data indicate that the build-up of phosphorus concentrations in these waters peaked in the early 1970s. The subsequent decline in phosphorus concentrations is apparently a response to phosphorus controls, which began in the early 1970s.

Northern Inland Waters

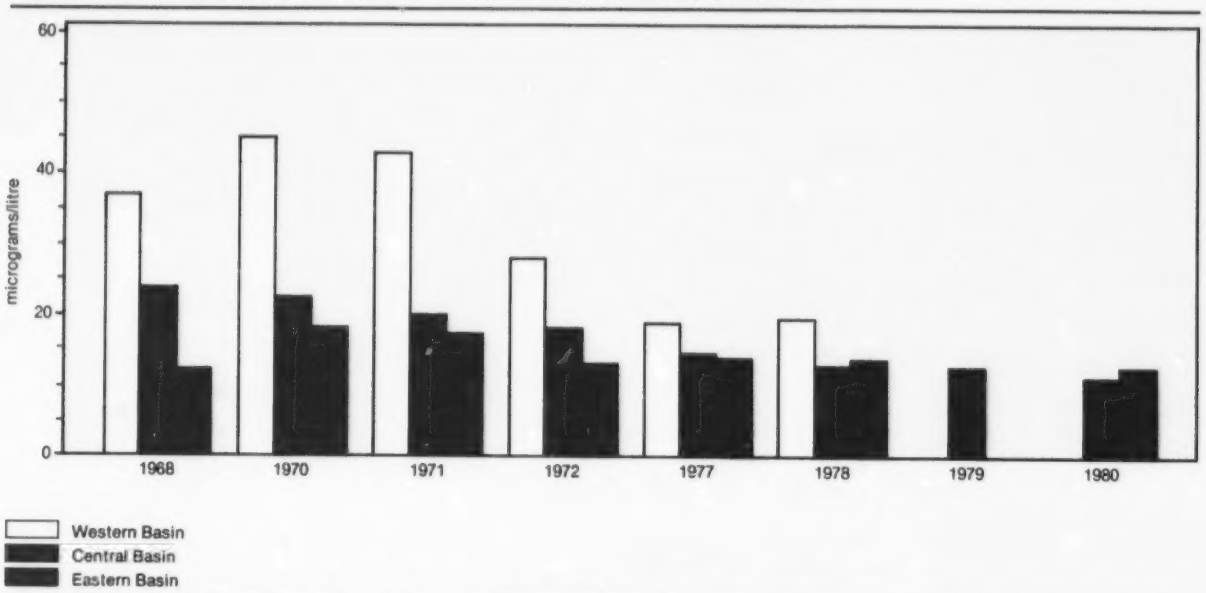
Indicators on the state of northern inland waters would reflect stress characteristics resulting from human activities such as large-scale resource exploitation and the widely scattered Native peoples' settlements in this thinly populated region. Data on the state of aquatic ecosystems are scarce, and what is

Figure 5.7
Mean Soluble Reactive Phosphorus Concentrations in the Basins of Lake Erie, 1968-1980



Source: Environment Canada, *Statistical Assessment of the Great Lakes Surveillance Program, 1966-1981*, edited by A.H. El-Shaarawi, Lake Erie Scientific Series No. 136 (Burlington, Ont.: National Water Resources Institute/Canadian Centre for Inland Waters, 1984).

Figure 5.8
Mean Total Phosphorus Concentrations in the Basins of Lake Erie, 1968-1980



Source: Environment Canada, *Statistical Assessment of the Great Lakes Surveillance Program, 1966-1981*, edited by A.H. El-Shaarawi, Lake Erie Scientific Series No. 136 (Burlington, Ont.: National Water Resources Institute/Canadian Centre for Inland Waters, 1984).

available is, at best, illustrative of the potential impact of development on the ecology.*

Most Canadian inland waters are in a temperate climate; northern inland waters, however, are under a much harsher physical and climatic regime, with a shorter growing season and lower average temperatures, life cycles that are compact, and ecosystems that are less complex than further south. A federal-provincial study of water and related resources in the Mackenzie River basin recognized the annual spring ice breakup as a most important hydrological event. The high productivity of alluvial ecosystems depends on the annual spring breakup and subsequent flooding. Deltas in particular exert an influence far greater than their size and provide an ecological complexity that depends on the annual deposition of alluvial material. The Mackenzie River basin contains three significant deltas, the Peace-Athabasca, the Slave and the Mackenzie.

Other studies of lakes in the high Arctic, arctic islands and peninsulas, e.g., Lake Hazen on Ellesmere Island, reveal that water itself is important because of the extreme aridity of the region. This precludes abundant vegetation anywhere but adjacent to ponds, streams, lakes and seepage areas. Lakeside sedge meadows make up the greatest proportion of the local biomass and food webs. The high arctic environment is vulnerable to disturbance because of the short growing season, low temperatures and severe aridity. Since reliable water is in short supply, sediment loading or the introduction of sewage or toxicants may result in long-term perturbation of these systems.

INFLUENCES ON THE GREAT LAKES AND OTHER FRESHWATER ECOSYSTEMS

Aquatic systems are influenced by a wide range of forces, both human and natural. These include harvesting of commercial fish, habitat transformation (especially wetland drainage, dams and alterations of the foreshore), pollution, introduction of exotic species, diseases, and climatic changes.** Harvesting, physical restructuring, nutrient loading and introduction of non-native species are described in this chapter; contaminants are covered in Chapter 8.

Harvesting

The most significant harvests of freshwater fish in Canada are obtained from the Great Lakes, in particular, Lake Erie. From about 1820 to 1870, fish landings of most species from Lake Erie rose swiftly as a commercial fishery developed. Since that time, fishing pressures have been maintained at relatively high levels, while stock after stock of the more economically valued species has collapsed.[5]

In Lake Ontario, over-harvesting also appears to have played a role in transforming the fish community. Of the 10 most highly valued species, only three (yellow walleye, American eel and yellow perch) are now found in significant quantities. Lake whitefish, once abundant, has declined to precariously low levels over the past 25 years as a result of over-harvesting, although over-enrichment and pollution have also played a role.

Physical Restructuring

Land-based activities and direct interference with natural water flows have deprived fish of their spawning habitats in a number of regions. There are many processes involved: drainage of wetlands for agriculture, urban and industrial expansion; accelerated sedimentation from soil-eroding practices in forestry, agriculture and construction; dam construction and water diversions; and such practices as quarrying and dredging lake bottoms.

Three of these influences are documented here: the disappearance of wetlands; sediment loadings; and physical restructuring.

Disappearance of Wetlands

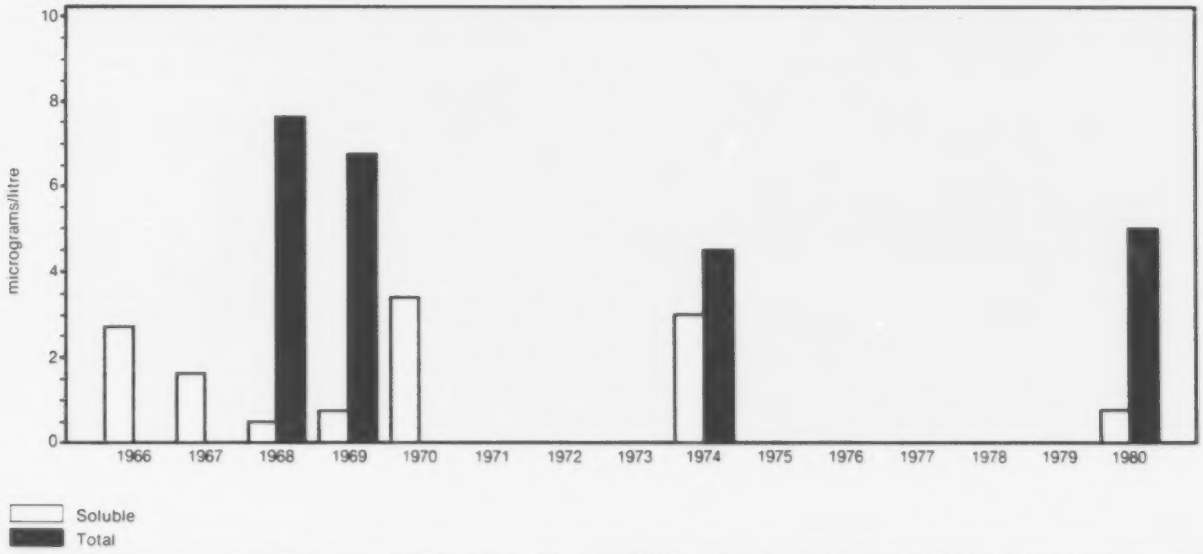
Wetlands provide staging and breeding areas for waterfowl and some fish species and feeding grounds for certain fish at various stages in their life cycles. They are an essential habitat for hundreds of species of invertebrates, plankton and leafy plants (macrophytes). Shoreline wetlands have been disappearing as a result of pressures from agriculture, urbanization and recreation. Based on historical maps, the wetland area along Lake Ontario from the Niagara River to the Bay of Quinte is estimated to have been about 4 500 hectares (ha) at the time of early settlement. Today, little more than 2 500 ha remain — a loss of nearly 50 per cent (Table 5.11). Much of the loss of wetlands around Lake Ontario was concentrated in the western, heavily urbanized and industrialized region. Over a recent period (1965-1979), the wetlands of Lake St. Clair decreased by 1 600 ha (44.8 per cent), mainly as a result of land reclamation for agriculture.

Four basic wetland types are recognized in the aquatic habitat of the Lake Champlain and Richelieu River basin. Although few of the 52 000 acres of wetlands, which make up less than 1 per cent of the basin area, are located in Canada, they do contribute significantly as fish spawning habitat and as staging and breeding areas for migratory birds and aquatic furbearers. In addition to the intrinsic and commercial value of this aquatic environmental component, recommendations by the International Joint Commission favour wetlands as non-structural solutions to the flooding problem.

*The requirement for environmental impact assessments for major development proposals has resulted in a growing bank of baseline data linked to specific northern development projects.

**These influences can be more finely categorized. See, for example, the classification of stresses affecting the Great Lakes, reference #5.

Figure 5.9
Mean Soluble and Total Phosphorus Concentrations, Lake Huron, 1966-1980



Source: U.S. and Canadian agencies. Available on U.S. Environmental Protection Agency STORET system.

Table 5.11
Estimated Wetland Change on the Canadian Side of Lake Ontario, 1789-1979[1]

Shoreline Region	Maximum Historical Wetland (1789-1962)	Recent Wetland (1977-1979)	Net Decrease	Percentage Change[2]
		hectares		
Niagara River to Burlington Bay	476	127	348	73.2
Burlington Bay and Dundas Marsh	457	117	340	74.5
Burlington Bay to Toronto Bay	270	51	220	81.2
Toronto Bay and Ashbridge's Bay	610	0	610	100.0
Toronto Bay to Presqu'Ile	827	566	261	31.6
Presqu'Ile to Bay of Quinte	1 867	1 727	140	7.5
Total estimated	4 507	2 588	1 919	43.1

[1]Approximately 3 240 ha, or 72 per cent of the historical marsh were measured from maps. The remainder was estimated based on regional percentage changes that occurred for the measurable portion.
[2]1977-79 wetland as percentage of estimated maximum wetland, 1789-1962.
Source: T.H. Whillans, "Changes in marsh area along the Canadian shore of Lake Ontario", *Journal of Great Lakes Research* 8/3 (1982): 570-577.

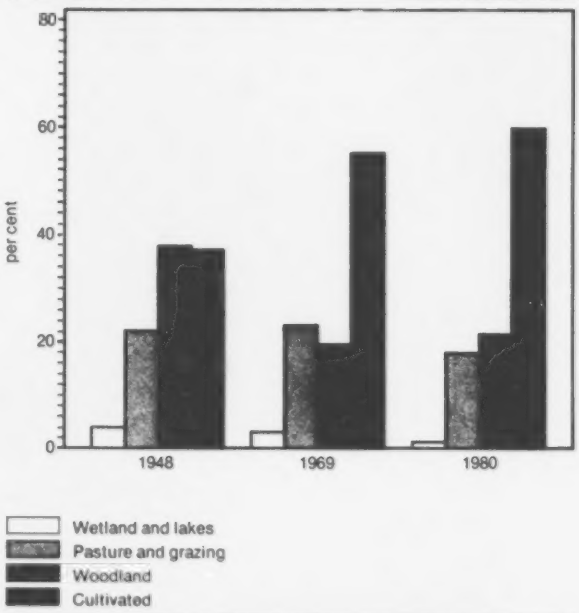
The substantial increase in cultivated land in the Dauphin Lake watershed at the expense of wetlands and woodland is shown in Figure 5.10. Other transformations such as channelization of tributaries and altered seasonal stream flows due to municipal sewage, have increased siltation in fish spawning areas and led to nutrient enrichment of downstream waters. These factors together are believed to be responsible for the changes in the Dauphin Lake fishery[10] (see Tables 5.8 and 5.9).

Sediment Loading

Excessive silting of lakes, rivers and estuaries renders spawning grounds unproductive. It is a common by-product of urbanization, as well as agricultural, forestry and other practices that accelerate soil erosion. In the lower Great Lakes, Lake St. Clair and Lake Huron, data on the annual mean suspended sediment loadings for important tributaries are available, although incomplete. These data show a tendency towards increased loadings. The relationship of sediment loading to construction activity for the Don River (Toronto) watershed is shown in Figure 5.11. This area has been subject to episodes of road building and urbanization in recent decades. At the peak of these construction projects, the Don was depositing nearly 400 000 tonnes of sediment annually, an amount more than 10 times greater than the sediment deposits coming from Big Creek, a partially-reforested watershed twice its size. In recent years sediments from the Don have decreased as the land stabilized following the peak construction period and as a result of conservation and clean-up measures taken by local and provincial governments.

A recent study of Dauphin Lake[7] indicated that more than 500 000 tonnes of suspended sediments plus bed load per year were deposited in the lake for the period 1950-1980, with infilling estimated at a rate of two inches per 100 years. Since the formation of the lake approximately 8 000 years ago, more than eight metres of sediments have accumulated. At the present rate of infilling, the lake could be completely filled with sediments in about 2 000 years.

Figure 5.10
Trends in Land Cover (as a percentage of total) in the Dauphin Lake Study Area



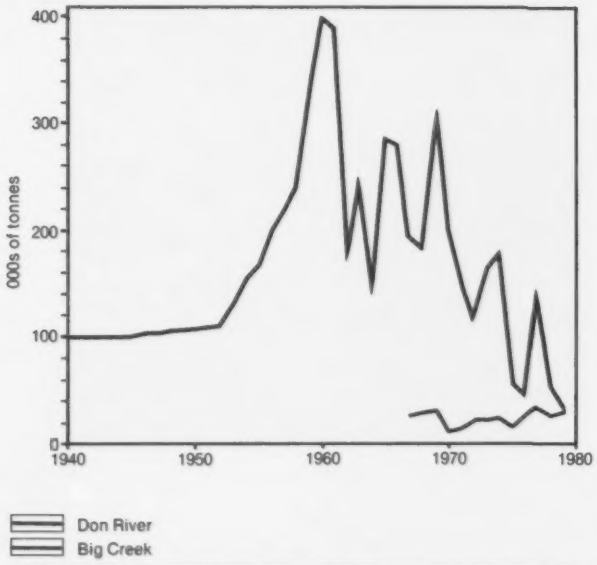
Source: H. Pokrant and M. Gabourg, *Remote Sensing to assess land use/land cover changes affecting the Dauphin Lake fishery*, a report of the Remote Sensing Centre, Manitoba Surveys and Mapping Branch, Department of Natural Resources, 1983.

Physical Restructuring

Dams and water diversions for hydro-electric power or agricultural purposes may introduce obstructions to migrating fish or link species that were formerly isolated. New interchanges could be potential sources of stress to once separate ecosystems. Other aspects of the aquatic environment that may be changed by physical restructuring include concentrations of nutrients, degree of siltation, and oxygen concentrations, which have a bearing on aquatic biota. Moreover, the restructuring of shorelines modifies terrestrial wildlife habitat.

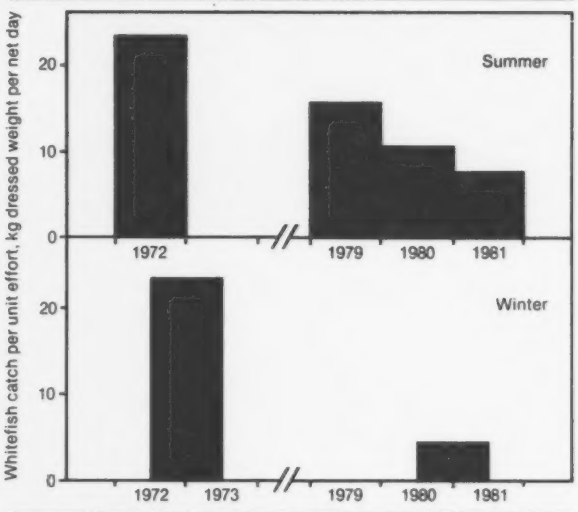
In 1977, most of the upper Churchill River was diverted to the Nelson River at Southern Indian Lake. This reduced the water flow to the lower Churchill River, which empties into Hudson Bay on its western shore, from 1 010 to 220 cubic metres per second. The diversion raised the water level of Southern Indian Lake by approximately three metres, resulting in a 20-per cent increase in surface area and a 39-per cent increase in volume over long-term mean values. This in turn increased total shoreline erosion rates from less than 5.9 per cent to 80 per cent as water reached the fine-grained tills and lacustrine silty clays, which previously existed in permafrost. The result was a rise in turbidity — to as much as 8 times original values in some areas of the lake — and a 30- to 50-per cent drop in light penetration. The diversion also delayed the departure of ice from large portions of the lake and lowered mean temperatures. Perhaps the most significant effect of the impoundment was the reduction in both the quantity and the quality of commercial catches of lake whitefish. Southern Indian Lake had at one time the largest whitefish fishery in northern Manitoba. The catch was characterized as 'export grade' prior to impoundment, but 5 years later the classification was lowered to 'continental grade'. Lower-grade fish (those with darker color and higher parasite counts) were nearly absent from pre-impoundment catches but made up 12 to 72 per cent of the catch in the 4 years following impoundment. This was because the fishery expanded to new areas when catch per unit effort declined in traditional areas. At the same time, the catch per unit effort declined to one-third that of the pre-impoundment mean. Catch per unit effort before and after impoundment are compared in Figure 5.12. Much of the change in fish populations can be attributed to changes in the distribution of whitefish stocks after impoundment and to physical conditions that affected spawning success. Both increased sedimentation from the eroding shores of Southern Indian Lake and flooded shores

Figure 5.11
Sediment Loadings from the Don River and Big Creek to Lower Great Lakes, 1940-1979



Source: Acres Consulting Services for Metropolitan Toronto and Region Conservation Authority, Main Report of the Keating Channel Environmental Assessment, 1983.

Figure 5.12
Lake Whitefish Catch per Unit Effort in the Southern Indian Lake Commercial Fishery



Data are from pre-impoundment (1972 summer and 1972-73 winter) and post-impoundment (1979-1981 summers and 1980-81 winter).

Source: R.A. Bodaly et al., "Collapse of the Lake Whitefish *(Coregonus clupeaformis)* Fishery in Southern Indian Lake following Lake Impoundment and River Diversion", *Canadian Journal of Fisheries and Aquatic Sciences* 41 (1984): 692-700.

and terrestrial vegetation probably decreased the quality of the whitefish habitat.

The Peace-Athabasca Delta (3 900 square kilometres of lowlands near the western end of Lake Athabasca) constitutes a highly productive wetland. It is characterized by shallow water, high fertility and a relatively long growing season. The delta is a staging area for geese and ducks en route to the Mackenzie River lowlands and is the winter foraging and summer calving ground for the world's largest herd of free-roaming bison. It is one of the largest boreal deltas in the world.

Alteration of the hydrological pattern in the delta as a consequence of construction of the Bennett Dam on the Peace River and the filling of the Williston Reservoir (1968-1971) may have permanently disrupted the natural processes of the delta.*

Before the Peace River came under controlled flow, the Peace-Athabasca Delta ecology was tuned to the natural hydrological cycle. Spring and summer runoff would flood the delta in July, filling the many lakes and channels and flushing out perched basins or sloughs. By late summer, the water level in Lake Athabasca would recede, with a subsequent fall in the surrounding water table, reaching minimum levels in March.

This cycle maintained numerous perched marshes, replenished groundwater supply, retarded advancing plant succession, and deposited nutrients and suspended sediments from the river system. Accumulated salts were flushed from the soil, preserving a favourable chemical balance. In fall the receding water exposed sedges (a wetland type characterized by grasslands) that provided winter forage for bison.

The Bennett Dam fundamentally changed this hydrological regime. Since a significant amount of spring and early summer runoff is stored, peak flows have been reduced, and the critical annual flooding and recharging process has been suppressed. Furthermore, in former times, the peak flows of the Peace River (mid-May to mid-July) would overflow into the delta and act as a natural reservoir, retarding the outflow of water from the delta and Lake Athabasca.

These hydrological changes have affected the large number of fish using the delta and the Athabasca, Peace and Slave River systems as well as Lake Athabasca. These species include the valuable

*The effect of the construction of the Bennett Dam on waterfowl habitat in the delta is documented in Chapter 6.

Table 5.12
Present[1] and Potential Trout and Salmon Migration Routes in the Great Lakes

	Routes Fully Open	Routes Partly Blocked	Potential Beyond Barrier	Total	Dam with Fishway	Partial Dam	Full Dam	Natural Barrier
	kilometres[3]				number of structures			
Lake Ontario Tributaries	246	187	2 397	2 830	0	5	51	2
Lake Erie Tributaries	259	6	1 105	1 370	1	1	19	—
Lake Huron Tributaries[2]	584	35	1 527	2 146	1	2	10	1
Georgian Bay Tributaries	1 083	32	853	1 968	4	2	51	7
Manitoulin Island Streams	53	0	0	53	0	0	0	0
North Channel Tributaries	124	0	14	138	0	0	0	0
Lake Superior	1 091	138	809	2 038	1	14	15	96
Total	3 440	398	6 705	10 543	7	24	66	103

[1]As of 1976.
[2]The main basin of Lake Huron but excluding Georgian Bay, Manitoulin Island and the North Channel streams.
[3]Original data reported in miles. Data rounded to nearest kilometre.
Source: Ontario Ministry of Natural Resources, "Trout and Salmon migratory routes, Southern Ontario streams", Map SF-1 (1973); "Trout and Salmon migratory routes, Southern Ontario streams", Map SF-5 (1976).

walleye and goldeye which use the delta for spawning and as habitat for young fish.

Since 1971, under the recommendations of the Peace-Athabasca Delta Implementation Committee, efforts have been made through controlled flooding to reverse the effects of the low-water years in the western part of the delta. However, many perched basins have not been recharged, and these are now overgrown with willow bush.

In the Great Lakes basin, man-made barriers have hindered the potential migration routes of some fish species, especially in the lower lakes (Table 5.12). This condition has been improved somewhat by the construction of fishways (bypassing the obstruction) and the removal of small mill dams. Nonetheless, many miles of stream remain inaccessible to migratory fish.

Nutrient Loadings

Over the past century, the growth of human settlement, agriculture and industry along the shores and drainage basins of the Great Lakes has added considerable phosphorus to the waters, resulting in increasing eutrophication of the nearshore and offshore surface waters of the lower Great Lakes and certain regions of the upper lakes.

Table 5.13 provides a summary of phosphorus loadings from 1976 to 1982 in the Great Lakes and in the St. Lawrence River up to Cornwall. These annual estimates, produced for the International Joint Commission, demonstrate the relative success of the control of direct point-source loading (i.e., sewage outlets and industrial discharges) and the difficulty of achieving equivalent success in the control of non-point sources (i.e., stream flows into the Great Lakes and the St. Lawrence, interbasin flows, and atmospheric fall-out). Nonetheless, the target loads (based on Canada-U.S. agreements on the assimilation capacity of individual lakes) are generally being met. Fertilizer runoff from agriculture is now considered one of the major remaining problems in controlling phosphorus loadings in the Great Lakes.

Other lakes in the populated basins of Canada show typical signs of eutrophication, for example, Missisquoi Bay on Lake Champlain — a relatively shallow basin with little current. Similarly, slow-flowing rivers draining intensively cultivated agricultural lands are highly susceptible to high levels of weed and algae growth, e.g., the Yamaska, Rideau and Thames Rivers.

The Lake Winnipeg drainage basin showed a 1- to 3-per cent annual increase in livestock and human populations and in cultivated land, and a 13-per cent annual increase in agricultural fertilizer use between 1950 and 1980. Nutrient supply rates to Lake Winnipeg and other prairie lakes were probably high before 1800, but agriculture and city sewage systems have increased loadings. It has been estimated that, between 1960 and 1970, nutrient loadings were greater in the south basin of Lake Winnipeg than in Lake Erie. Lake Winnipeg is shallow and well mixed and is capable of flushing much of this load to outflow. A comparison of surveys from 1925-1930 and 1969-1970 shows little change in nutrient concentrations in the lake.

Table 5.13
Phosphorus Loadings in the Great Lakes, 1976-1982

	1976		1977		1978		1979		1980		1981		1982	
	tonnes	%	tonnes	%	tonnes	%	tonnes	%	tonnes	%	tonnes	%	tonnes	%
Lake Erie:														
Point Source[1]	6 006	39	5 832	40	4 631	24	2 890	24	2 452	17	1 898	18	1 455	12
Non-Point Source														
Tributary	7 211	47	6 545	45	12 874	66	6 421	54	9 773	66	6 745	65	9 154	74
Interbasin transfer	1 080	7	1 080	7	1 080	6	1 080	9	1 080	7	1 080	10	1 080	9
Atmospheric fall-out	1 119	7	1 119	8	879	4	1 550	13	1 550	10	729	7	660	5
Total	15 416	100	14 576	100	19 464	100	11 941	100	14 855	100	10 452	100	12 349	100
Percentage from Canadian Sources[2]		14		24		12		22		22		16		23
Target Load[3]	14 606		14 606		11 000		11 000		11 000		11 000		11 000	
Lake Ontario:														
Point Source[1]	2 119	17	2 594	29	2 030	19	2 419	27	2 122	25	1 818	25	1 643	18
Non-Point Source														
Tributary	4 490	35	2 970	33	2 899	26	3 200	36	3 059	36	2 435	33	3 318	37
Interbasin transfer	5 613	44	2 748	31	5 250	48	3 058	34	3 087	36	2 856	38	3 330	38
Atmospheric fall-out	473	4	623	7	764	7	311	3	311	3	328	4	600	7
Total	12 695	100	8 935	100	10 943	100	8 988	100	8 579	100	7 437	100	8 891	100
Percentage from Canadian Sources[2]		39		38		48		51		51		51		50
Target Load[3]	9 072		9 072		7 000		7 000		7 000		7 000		7 000	
All Lakes:[4]														
Point Source[1]	9 595	26	9 802	31	7 739	20	6 252	17	5 568	15	4 536	18	3 893	14
Non-Point Source														
Tributary	21 248	59	16 017	51	24 517	62	18 432	51	20 631	55	17 750	72	21 500	75
Atmospheric fall-out	5 433	15	5 583	18	7 284	18	11 157	32	11 157	30	2 481	10	3 393	11
Total	36 276	100	31 402	100	39 540	100	35 841	100	37 356	100	24 767	100	28 786	100
Percentage from Canadian Sources[2]		24		29		22		29		30		26		30
Total Target Loads of Individual Lakes[5]	32 562		32 562		31 360		31 360		31 360		31 360		31 360	

[1]Includes direct municipal and industrial discharge.
[2]Excludes interbasin transfer and atmospheric sources.
[3]Target phosphorus loads established by the Canada-U.S. Great Lakes Water Quality Agreement.
[4]Includes St. Lawrence River, up to Cornwall (i.e., area under jurisdiction of the International Joint Commission).
[5]Target loads for the individual lakes are arrived at through bilateral negotiation and by using modelling estimates of the capacity of each lake to assimilate phosphorus loads. An agreement to reduce tributary loadings (runoff from phosphorus-containing fertilizer) was signed in 1983 between Canada and the United States. The new target will be set in 1985.
Source: Great Lakes Water Quality Board, Reports to the International Joint Commission, *Great Lakes Water Quality*, 1976, 1977, 1978, 1981 and 1983.

Historically, most nutrient loading to the Qu'Appelle watershed in Saskatchewan and Manitoba has come from sewage disposal at Regina and Moose Jaw and from nearby agricultural land. Establishment of tertiary sewage treatment facilities in Regina in 1977 served to reduce phosphorus loads to the Qu'Appelle River from Wascana Creek, leaving Moose Jaw as the biggest single point-source of phosphorus.

The situation is further complicated by the tendency of the Qu'Appelle River to flood. Channel improvements will be carried out under a five-year federal-provincial agreement that took effect in April 1984.

Phosphorus and nitrogen monitoring between 1980 and 1983 indicated reduced concentrations downstream from the naturally eutrophic lakes of the Qu'Appelle Valley. It is believed that this may be due, in part, to the greater retention and utilization of nutrients by algal communities — a particular concern given that the lakes are used for recreation and are a source of water for agriculture and municipalities in the Regina-Moose Jaw region.

Introduction of Non-native Species

The introduction of non-native species, intentionally or accidentally, can result in significant restructuring of the ecosystem (see Tables 5.3 and 5.4). Some of the best documented examples of this process are in the Great Lakes, where non-native fauna now form major components of the system. Exotics displace native species (either by competition or predation) and alter other aspects of ecosystem behaviour. For example, in the Great Lakes, the rainbow smelt displaced important native species such as the lake herring.

The very presence of exotics often indicates a stressed environment. For example, in the lower Great Lakes, species such as alewife may thrive because of enriched offshore waters (from eutrophication) or because of the elimination of predators by overharvesting and other stresses. The invasion or introduction of an exotic usually adds a degree of uncertainty about the future state of an aquatic ecosystem. There is little to suggest that the presence of exotic species in these waters has abated in recent years.

The exotic Eurasian milfoil (a nuisance waterweed) appeared in Lake Champlain about 1950 and spread to other lakes in the basin in the 1960s and '70s. Control was attempted by physical removal, but the plants' capacity to reproduce defeated these efforts. The effect of milfoil on fish populations is not well understood. Nutrients from decaying milfoil are believed to contribute to local blooms of blue-green algae.

ASSESSMENT

This assessment summarizes some of the major effects of human activities on the Great Lakes and other freshwater ecosystems. As outlined in the introduction to this chapter, the complexity of ecosystems made it necessary to select components (indicators) of the system itself. These can be measured and are useful in managing resources. They do not, however, provide a complete picture of the ecosystem. Ideally, factors that regulate ecosystems need to be identified and their importance determined. Present data-collection processes are not based on this sort of understanding. The best compromise thus far developed for freshwater ecosystems is the basin management approach; in the future, data will be collected to meet this purpose. For example, biological components will gain emphasis, and the chemical and hydrological information now collected will be put into context.

In the vast unpopulated regions of Canada, the rivers and lakes remain, by and large, in a pristine state. Deterioration of water quality and threats to the viability of aquatic ecosystems are most severe in the southern ecozones — the Atlantic Maritime, the Mixed-Wood Plain, the Prairie and the Pacific Maritime — ecozones that make up about 11 per cent of the area of Canada but are home to about 85 per cent of the population. Nonetheless, the harvesting of forests, the construction of dams, the development of mines and the diffusion of man-made contaminants through hydrological flows and atmospheric cycles affect the health of aquatic life well beyond the boundaries of the settled regions of the country.

Canada accounts for some of the largest wetlands in the world. Nonetheless, there is continuing concern about the loss of critical wetlands in the southern reaches of the country (habitat for fauna and flora that could not survive in the harsh climate regimes of the north), as well as wetlands of local or regional significance. In the lower Great Lakes, nearshore marshes and wetlands provide feeding and breeding habitat for numerous fishes and waterfowl. The disappearance of these wetlands has been occurring since the beginning of European settlement, particularly with the drainage of lands for agriculture. Wetland losses have also occurred in the prairie agricultural region, the lower mainland of British Columbia, and areas linked to major dam construction. Wetland depletion is still continuing, but there is also increasing demand for their protection and conservation.

In the Great Lakes, ecosystem changes are reflected in changes in the quality of fish harvested by fishermen. Figure 5.2 shows a drastic decline in the proportion of high-value species in the commercial catch since the 1940s. This reflects a major restructuring of the ecosystem, with replacement of large native fishes by small exotic, opportunistic species. Over the past decade, as a result of efforts to stock harvestable fish, there is now a modest recovery in valued stocks.

With respect to eutrophication, a major concern of the 1970s, there have been signs that nutrient concentrations have begun to decline. This is attributable to effective programs initiated in the early 1970s to control phosphorus loadings from municipal sewage. In the Great Lakes this investment has clearly paid off in improved water quality with respect to nutrient loadings. Non-point source loadings, largely from agricultural runoff, remain a problem for the drainage basins with intensive agricultural activity, such as Lake St. Clair-Erie, the basins in the prairie region, the rivers and lakes in the Eastern Townships of Quebec, and the St. John-St. Croix basin in New Brunswick.

The contaminants question is now the predominant concern regarding aquatic ecosystems. This issue has direct bearing on risks to human health and, in some cases, may also jeopardize the health of fish stocks and wildlife. A good many contaminant levels appear to be declining (e.g., dioxin and PCB levels in herring gulls in the Great Lakes and mercury in fish in most Canadian streams). However, levels in many areas still exceed the various health guidelines (see Chapter 8). Further, there are continuing concerns about pollution from unstable landfill sites, e.g., the

Niagara River, where waste contaminants are leaching into groundwater and from there into lakes and rivers.

Acid precipitation remains one of the major threats to the viability of the ecosystems of thousands of small and medium-sized lakes in parts of the Boreal Shield and the Atlantic Maritime ecozones. A general overview and assessment of acid rain can be found in Chapter 8.

In summary, the abundance of freshwater lakes, and the many practically uninhabited drainage basins, place Canada in a unique position with respect to water resources. Although this country has not experienced the extreme levels of water degradation found in parts of the industrial world, nor the kind of competition for water found in densely populated Third World countries, an overall assessment of the state of Canada's aquatic ecosystems does not suggest grounds for complacency. Over-fishing has certainly led to the depletion or disappearance of freshwater fish stocks in some lakes and rivers. We still have much progress to make in rehabilitating the lower Great Lakes to a point where they could carry the high-quality fisheries of former days, or where the leakage of contaminants could be eliminated or where many beaches could be re-opened.

The loss of wetlands has undermined the viability of habitats for aquatic species in certain localities. Fortunately, awareness of the importance of these critical areas is now sufficiently high to anticipate increasing public demand for their conservation.

Other stresses to aquatic ecosystems are more difficult to control, as they are often an indivisible product of the technology of economic production or energy generation. The growth of fertilizer use, the application of pesticides, and runoff from feedlots have clearly had detrimental effects on the quality of the water that drains the intensively cultivated agricultural regions of Canada.

The problem of how to control the spatial diffusion of chemical contaminants, including their manifestation as acid rain, is still far from any satisfactory solution.

The demand for cheap (and pollution-free) energy from hydro-electric power has, given the scale of these development projects, drastically altered the hydrological regimes in many remote parts of the country.

Finally, we cannot ignore the potential effects of large-scale interbasin transfers — or for that matter, climate change — on aquatic ecosystems. The Inquiry on Federal Water Policy[9] recognized the urgency of planning and responding to the high likelihood of demands for water transfer from the 'surplus' north-flowing rivers to the water-deficient basins in the western and mid-western United States.

ATLANTIC MARINE ECOSYSTEM

INTRODUCTION

For purposes of this report, the Atlantic marine ecosystem encompasses the region from Cap Chidley in the north to Georges Bank in the south, the St. Lawrence River and its estuaries as far west as the Saguenay River, and the offshore waters northeastward to the coast of Greenland. We have considered this vast region as one marine zone (Figure 5.13), primarily from the fisheries perspective. The extensive migrations of many marine fishes and mammals, as well as of anadromous-catadromous species, would render a smaller partitioning cumbersome.

Within this region, ecological communities of the most diverse types can be found. Shallow rich estuaries and bays provide an ideal habitat for shellfish such as oysters, clams and mussels. The great fishing banks have for centuries produced large catches of a variety of fish species, especially cod. Oceanographic features such as currents, tidal flows and upwellings are important in determining the interactions of the fish, mammalian, invertebrate and plant communities.

The region can be subdivided on a number of bases. An oceanographer would distinguish the fresh and brackish waters of the St. Lawrence from the cold marine Labrador Current to the north and the warm marine Slope Water Current and Gulf Stream from the south (Figure 5.13). An economist would differentiate the inshore fishery (small vessels, usually fishing within sight of land on a seasonal basis) from the larger, year-round offshore fishery. The fishery can be further divided into the crustacean or shellfish, ocean, and anadromous-catadromous fisheries. (The latter species spend part of their lives in salt water and part in fresh water; the Atlantic salmon is a notable example.) A strict ecological study would consider subsystems such as bays, estuaries and banks. This section considers the whole, keeping in mind the diversity of its parts.

The next section describes the criteria used to assess the state of the Atlantic marine ecosystem. Then we look at major influences, including harvesting, pollution, physical restructuring, the introduction of exotics, and climate change. In the final section we offer an overall assessment of the state of the Atlantic marine ecosystem, drawing together some interrelationships between conditions and influences.

STATE OF THE ATLANTIC MARINE ECOSYSTEM

A number of ideal indicators could be used to reflect conditions in the Atlantic marine ecosystem. These would include primary productivity, biotic composition (reflected in changes in the abundance of commercial fish stocks), the size spectrum of biota, disease

Figure 5.13
Ocean Currents Affecting the Atlantic Marine Ecosystem

Source: Department of Fisheries and Oceans, *Canadian Atlantic Offshore Fisheries Atlas*, edited by D.J. Scarrett (Ottawa: Fish Management Branch, 1982).

Table 5.14
Commercial Landings of Finfish from Canadian Atlantic Waters by All Countries
(thousands of tonnes, round weight)

	Cod	Haddock	Redfish	Flatfish	Halibut	Silver hake	Herring	Pollock	Mackerel	Capelin	Total[1]
1883	441	2	0	0	NA[5]	NA	NA	NA	NA	NA	NA
1903	429	7	0	0	2.4	0	NA	NA	NA	NA	525
1923	528	26	0	0.3	3.5	0	64	NA	NA	NA	653
1933	475	48	0	1	2.9	0	65	NA	NA	NA	600
1943	407	29	4	2	1.0	0	130	NA	NA	NA	650
1953	489	81	66	38	2.8	0	90	NA	NA	NA	1 072
1963	900	65	81	64	3.4[3]	123	118	33	6	6	1 589
1973	709	19	252	214	1.8	299	139	30	38	269	2 292
1983[2]	583	35	104	97	1.6	36	141	47[4]	25	40	1 110

Trends shown in this table generally reflect the growth of the fishery to 1963. After 1963, the fishery came under increasing regulation. The first stock assessments were done in 1972, and quotas were set on total allowable catch by all nations from 1976 on. Since 1977, the foreign fishing pressure has become better controlled, and consequently the data more reliable.

[1]Total includes minor species not detailed in table.

[2]Preliminary data.

[3]Figure doubtful.

[4]Increase from 1973 reflects, in part, inclusion of Georges Bank in Canadian territorial waters.

[5]NA: not available.

Source: H.A. Regier and F.D. McCracken, "Science for Canada's Shelf-Seas Fisheries", *Journal of the Fisheries Research Board of Canada*, Volume 32 (1887-1982); Department of Fisheries and Oceans, *Resource Prospects for Canada's Atlantic Fisheries, 1985-1990* (in press).

outbreaks, and levels of contaminants found in both biotic and abiotic components.

While some information is available on each of these aspects, in almost all cases the data have considerable limitations. Primary productivity has been assessed for only limited time periods and regions. Major trends in biotic composition (e.g., fish populations) must be extrapolated from commercial catch statistics, which do not entirely reflect changes in the supplying stocks. Changes in size are recorded for only a few commercial species. The locations of outbreaks of some major diseases of marine fish and shellfish have been recorded; such ad hoc data indicate trends in incidence but cannot substitute for a systemic survey of disease incidence. Data on contaminants in aquatic birds are presented in Chapter 8. Also included here are data reporting shellfish harvesting closures as a result of toxic contamination. Indicators of stressed aquatic ecosystems are not available, and assessments of this kind can only be inferred from data collected for a variety of special purposes.

Primary Productivity

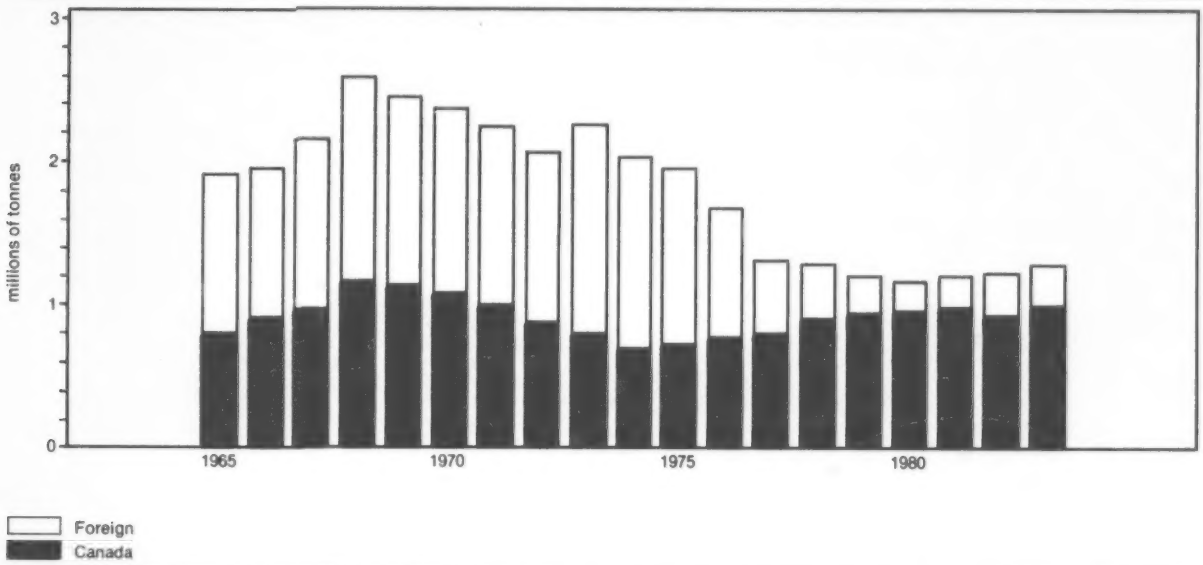
There are no comprehensive quantitative studies on the primary productivity of the Atlantic marine system as a whole. The Scotian Shelf Phytoplankton and Flemish Cap Programs (of the North Atlantic Fisheries Organization, hereafter NAFO) provide data on the productivity of sub-regions. A study of the Gulf of St. Lawrence provides data on primary and secondary productivity, based on surveys of ice-free periods from 1969 to 1972. These data hardly suffice to establish comprehensive baseline conditions. At best, they provide order of magnitude indications of productivity.

Primary productivity of the Gulf region shows considerable variation over time and area.[21] The region downstream from Pointe des Monts and southeastward through most of the lower estuary is the most productive area, and carbon fixation exceeds 200 milligrams per square metre per hour ($mg/m^2/h$) in the peak production period (April-May). As primary productivity in the lower estuary declines, peak production shifts to the middle estuary. At no time during the three-year study was the northeast region of the Gulf as productive; carbon fixation exceeded 50 $mg/m^2/h$ for only a brief period during spring bloom immediately following ice breakup, and chlorophyll a concentrations are less than 10 mg/m^2 from mid-May on. This part of the Gulf could be called a biological desert. The meaning of these data cannot be assessed properly without longer time series on trends and variations in primary productivity.

Biotic Composition

Ideally, it should be possible to examine changes in the community composition of fish and other important marine taxa. The data available do not yet permit this sort of community analysis. The alternative is to examine trends in the abundance of commercial spe-

Figure 5.14
Commercial Landings of Finfish, Canadian Atlantic Waters, 1965-1983



Source: Department of Fisheries and Oceans, *Resource Prospects for Canada's Atlantic Fisheries, 1985-1990* (in press). Data from North Atlantic Fisheries Organization, Statistical Bulletins.

cies, based on commercial catch statistics. Trends in the harvest of important species are in themselves a reflection of the capability of the ecosystem to provide sustainable yields of valued renewable resources. It must be remembered that economic, technological and social factors strongly affect trends in the commercial catch. Detailed knowledge of the factors surrounding fishing effort must be applied to each and every stock assessment. The data are for the most important species in terms of the volume or value of the landed catch, or for other species that are good indicators of environmental changes.

Table 5.14 shows trends in the commercial harvest of finfish in Canadian waters by all countries. Up to 1963, increases in landings were recorded for most species, reflecting growth in the fishery effort rather than conditions in the underlying stock. After 1963, commercial landings for many important species declined as fishing pressure intensified. The more recent history for all finfish is shown in Figure 5.14. The total commercial catch by all countries peaked in 1968 at approximately 2.5 million tonnes. Since that time, landings have declined precipitously, with current landings at approximately 1.3 million tonnes.

Trends in annual catch for several of the more important species of finfish are shown in Figures 5.15 and 5.16. Total landings of cod (Figure 5.15) peaked in 1968 and have since declined significantly to a low in 1977. The downward trend in catch reflects both over-harvesting and the effect of regulations imposed since the mid-1970s, when Canada began to exercise control on fishing in its 200-mile territorial zone. There has subsequently been a modest recovery.

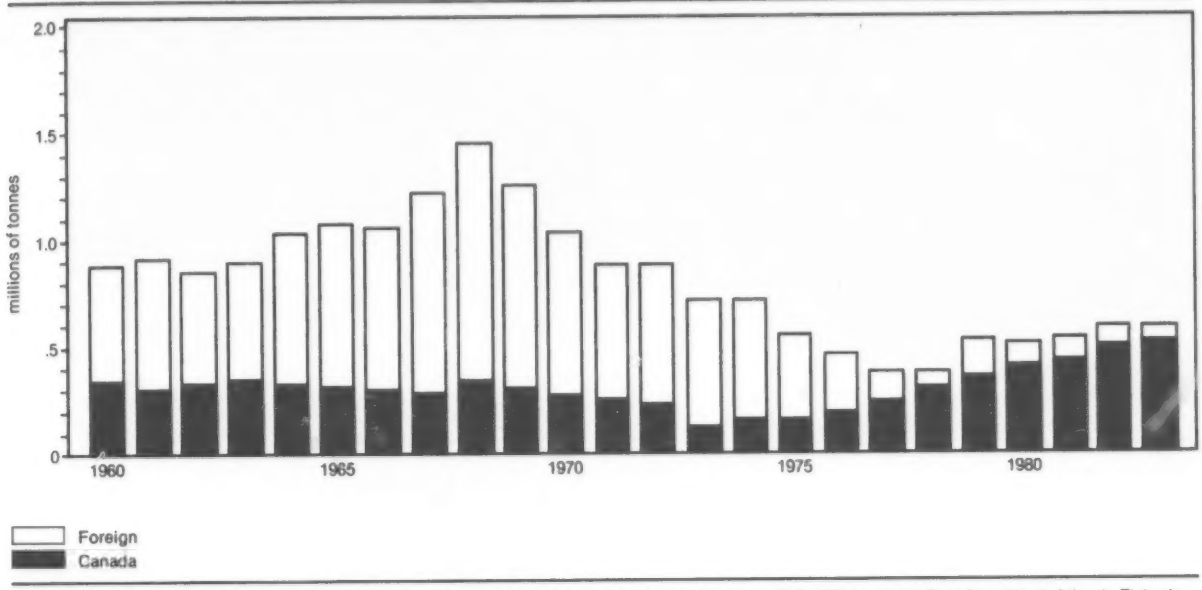
Herring (Figure 5.16) also shows a marked decline, with 1983 landings less than one-fifth of peak (1969) levels. The rapid decline in total catches of herring from 1970 to 1973 resulted primarily from a greatly increased fishing effort in the Gulf area. It began in the late 1960s, when west coast seiners arrived on the east coast after the west coast herring fishery was closed. Before then, Gulf herring stocks had been relatively lightly exploited. Current total commercial catches are approximately 100 000 tonnes, the lowest level in almost a quarter-century.

The bulk of the finfish catch consists of groundfish. Trends in commercial landings of this important component are given in Figure 5.17. These follow a pattern roughly similar to that for total finfish. In both cases, total catches declined significantly, while Canadian landings increased because quotas were reallocated from foreign to Canadian vessels.

Of all anadromous-catadromous species, Atlantic salmon is the most highly prized. Although it contributes a relatively small portion to the landed catch of all Atlantic marine species, it is important because of its sensitivity to environmental changes in the streams and rivers where it spawns, and because of public interest in the sports fishery.

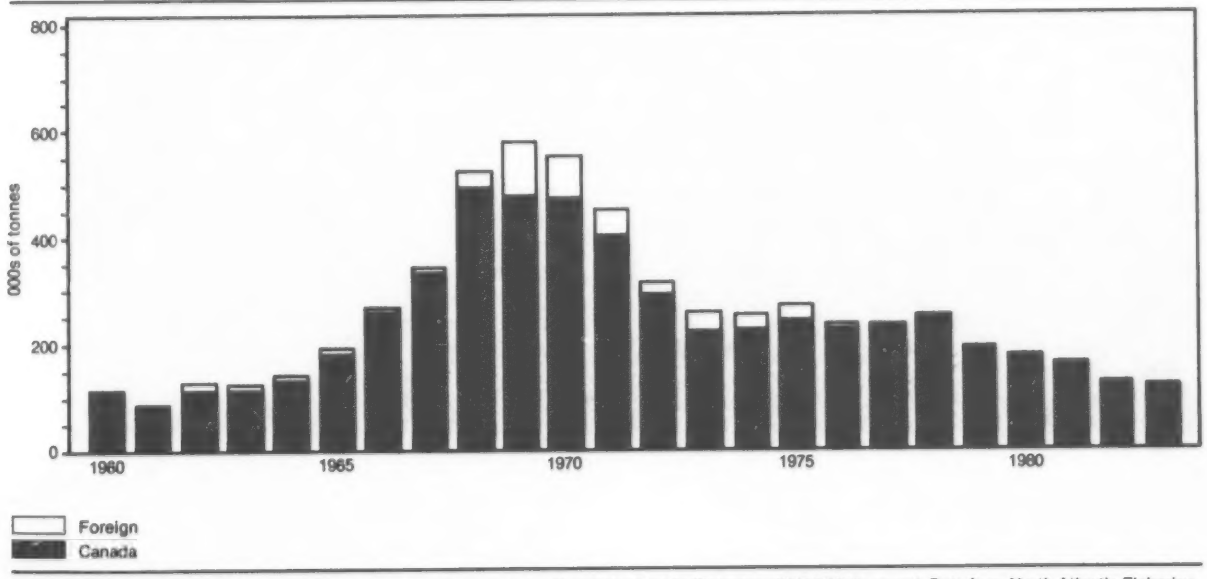
A peak of 6 000 tonnes of east coast salmon was landed in 1930. Subsequently there was a marked decline, which bottomed out in the mid-1950s. Over the past 30 years landings have fluctuated in the range

Figure 5.15
Commercial Landings of Cod, Canadian Atlantic Waters, 1960-1983



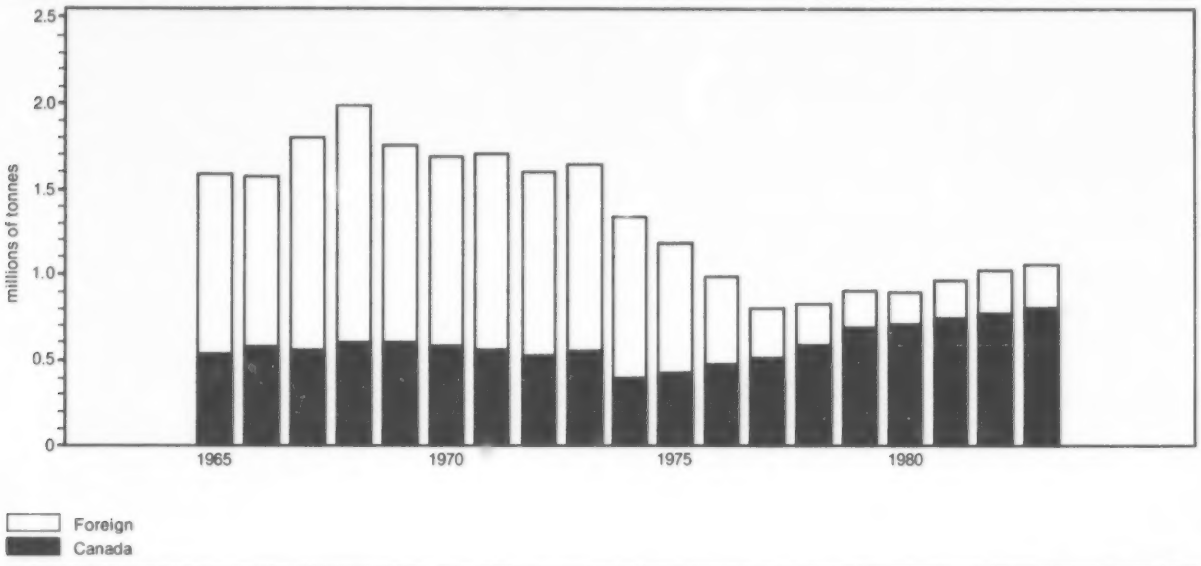
Source: Department of Fisheries and Oceans, *Resource Prospects for Canada's Atlantic Fisheries, 1985-1990* (in press). Data from North Atlantic Fisheries Organization, Statistical Bulletins.

Figure 5.16
Commercial Landings of Herring, Canadian Atlantic Waters, 1960-1983



Source: Department of Fisheries and Oceans, *Resource Prospects for Canada's Atlantic Fisheries, 1985-1990* (in press). Data from North Atlantic Fisheries Organization, Statistical Bulletins.

Figure 5.17
Commercial Landings of Groundfish, Canadian Atlantic Waters, 1965-1983



Source: Department of Fisheries and Oceans, *Resource Prospects for Canada's Atlantic Fisheries, 1985-1990* (in press). Data from North Atlantic Fisheries Organization, Statistical Bulletins.

of 1 500 to 3 000 tonnes. Recent landings are shown in Figure 5.18.

Lobster and scallops are the mainstays of the Atlantic invertebrate inshore fishery. Both species command a high price per unit weight; as a result, in spite of low volume, they rank second and third in economic importance to the east coast fishery. (Cod ranks first.)

By the 1890s the lobster fishery was fully developed; landings in 1898 exceeded 45 000 tonnes (Figure 5.19). Thereafter landings declined steadily until the early 1920s, reaching a low of approximately 12 000 tonnes in 1918. Subsequently landings have fluctuated between 13 000 and 23 000 tonnes. The preliminary data for 1983 indicate a landing of 28 000 tonnes, a recent record.

The recent history of scallop catches is shown in Figure 5.20. From less than 2 000 tonnes in 1950 (not shown), the harvest reached a peak of nearly 120 000 tonnes in 1977. Subsequently there has been a decline; current landings are in the range of 50 000 tonnes.

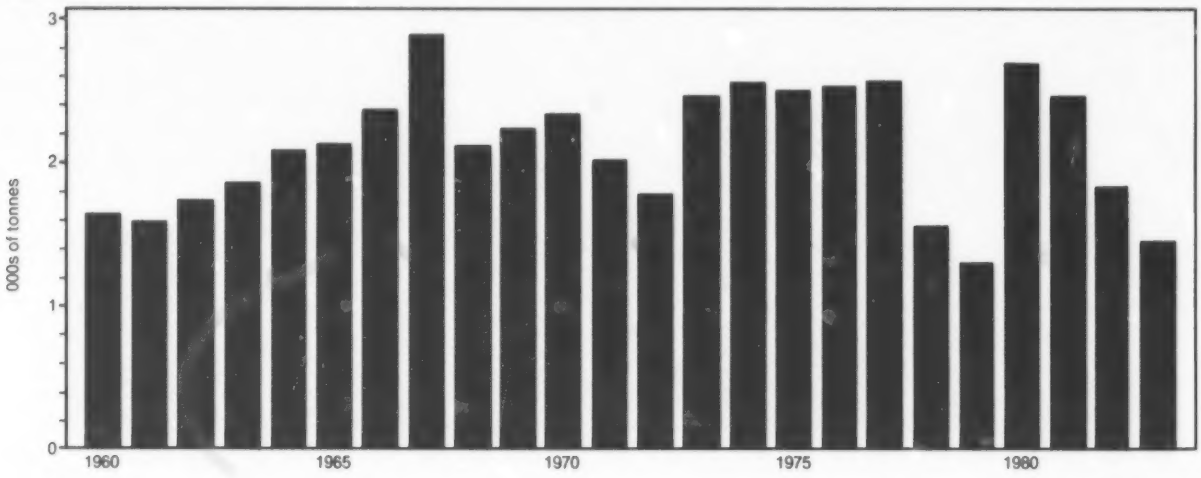
Until relatively recently (1973), almost no analytical stock assessments were undertaken for Atlantic fisheries. Over the past decade, increasing use has been made of scientific studies on stock abundance, but the assessments are still too limited to establish quantitative trends for major species. A qualitative assessment of change in major stocks since the peak harvest years (1967-1970) is given in Table 5.15.

Biotic Size

A workshop on multi-species approaches to fisheries management suggested that "heavy fishing pressure will tend to alter the ecosystem and the species remaining will tend to be smaller".[14] Unfortunately, there are no readily available data giving the size distribution for Atlantic fish stocks as a whole. For almost all fisheries of commercial importance, average life expectancy is reduced during the early fishing-up phase. This occurs as older fish of previously unfished stocks are caught preferentially. New recruits are not allowed to survive to comparable old age because they are caught when they are younger. In the lobster fishery, the fishing-up period presumably occurred before statistics were gathered on size distribution. By using generally accepted conversion factors, it is possible to take the recorded average weights for the early landings and convert them to lengths. On this basis, there is evidence indicating that the average carapace length in the late 1870s was 112 to 121 centimetres, compared to 80 cm in 1977 for lobsters off the western Atlantic maritime coast.[19,20]

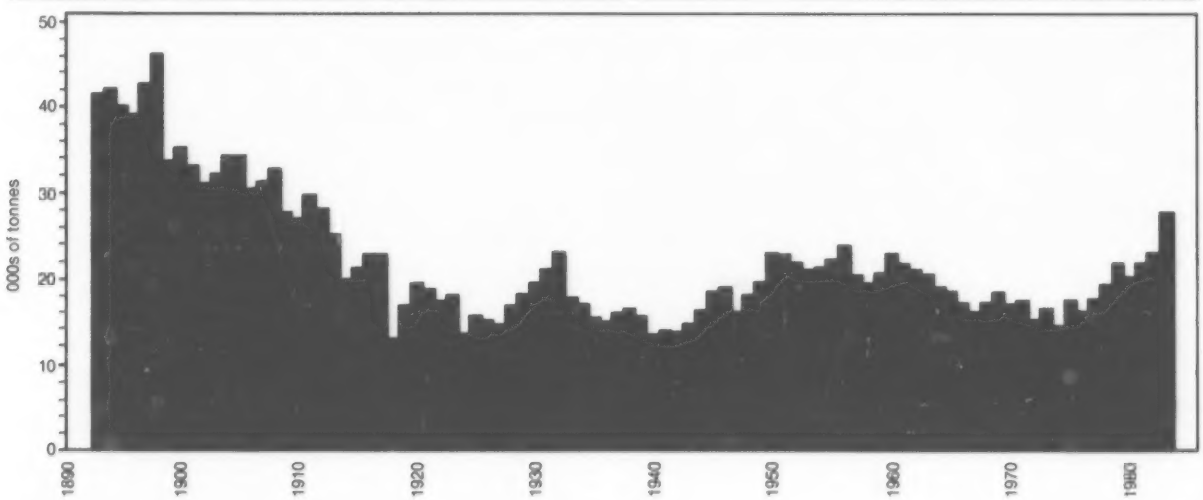
A better documented example of change in size (age) attributable to harvesting pressure is provided by the Gulf of St. Lawrence herring fishery. These stocks, which were harvested only lightly until the late 1960s, show a shift in age structure towards younger age classes from 1969 to 1981 (Figure 5.21).

Figure 5.18
Commercial Landings of Salmon, Canadian Atlantic Waters, 1960-1983



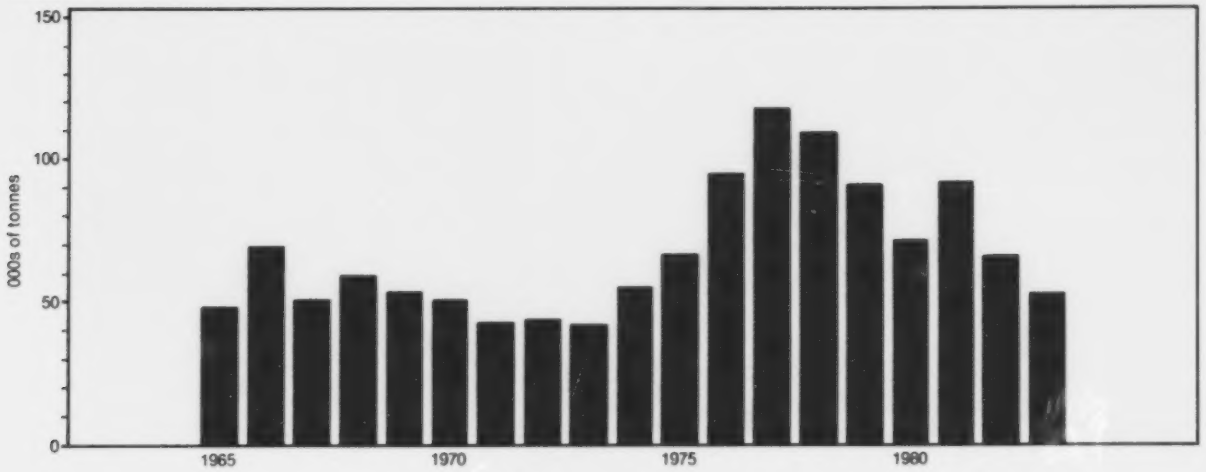
Source: Department of Fisheries and Oceans, *Resource Prospects for Canada's Atlantic Fisheries, 1985-1990* (in press). Data from North Atlantic Fisheries Organization, Statistical Bulletins.

Figure 5.19
Commercial Landings of Lobster, Canadian Atlantic Waters, 1893-1983



Source: Department of Fisheries and Oceans, *Resource Prospects for Canada's Atlantic Fisheries, 1985-1990* (in press).

Figure 5.20
Commercial Landings of Scallops, Canadian Atlantic Waters, 1965-1983



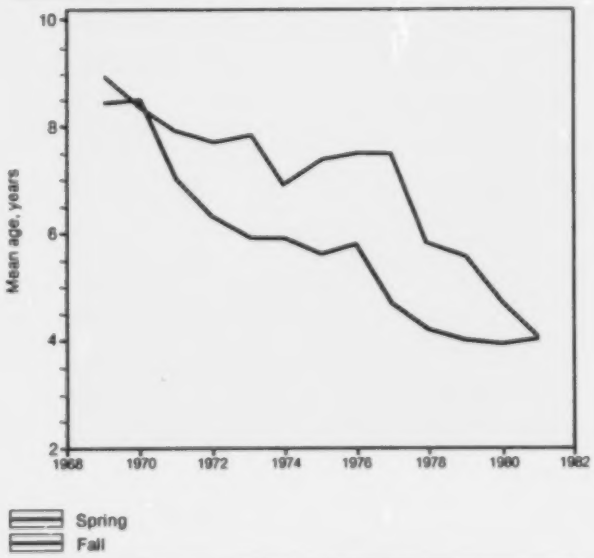
Source: Department of Fisheries and Oceans, *Resource Prospects for Canada's Atlantic Fisheries, 1985-1990* (in press). Data from North Atlantic Fisheries Organization, Statistical Bulletins.

Table 5.15
Qualitative Assessment of Change in Abundance of Major Atlantic Fish Stocks, 1970-1985

	Assessment of Direction of Change		
Stock	**Increase**	**Stable**	**Decrease**
Capelin			■
Cod			■
Flatfish		■	
Haddock	■		
Herring			■
Lobster	■		
Redfish		■	
Salmon			■
Scallops			■

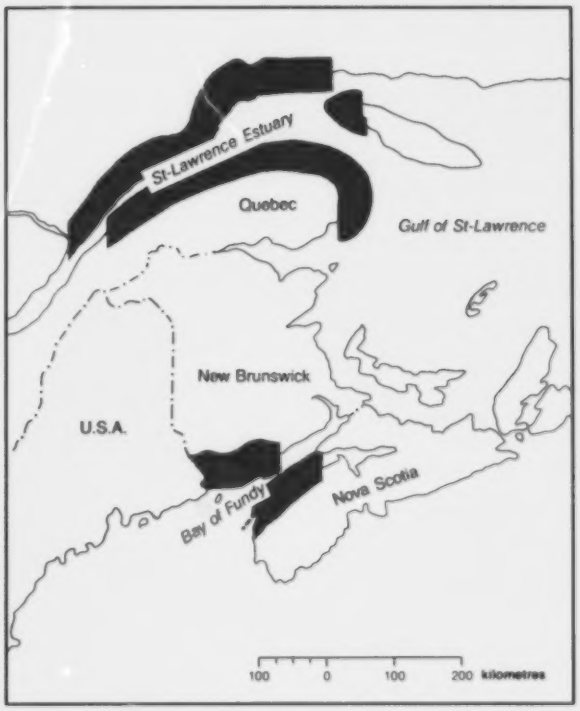
Source: Personal Communication, D. McCone, Department of Fisheries and Oceans, 1985.

Figure 5.21
Mean Age-at-Catch of Fall and Spring Herring in NAFO Division 4T, 1969-1981



Source: L. Cleary, "Assessment of 4T Herring Stock", Research Document No. 8247 (Quebec: Canadian Atlantic Fisheries Scientific Advisory Committee, 1982).

Figure 5.22
Locations of Toxic Blooms of *Gonyaulax* on the Canadian Atlantic Coast



Source: Department of Fisheries and Oceans, *Underwater World: Red Tides* (Ottawa: 1980).

Disease Incidence

The alga, *Gonyaulax excavata*, produces an extremely potent neurotoxin that becomes concentrated in filter-feeding shellfish such as clams (which are curiously immune to the poisonous effects). Paralytic shellfish poisoning, or PSP, has caused extensive mortality in fish and has potentially lethal effects on humans.[16,26] Figure 5.22 shows areas in eastern Canada closed to shellfish harvesting in 1980 because of suspected PSP outbreaks. Fortunately, the productive oyster areas along the New Brunswick north shore and in Prince Edward Island are not affected. In certain highly developed coastal areas in the world, such as Hong Kong harbour, various harbours in Japan and the Oslo fjord in Norway, there is good evidence that the increased incidence of blooms of *Gonyaulax* is related to increased outflow of municipal, industrial and domestic wastes. In eastern Canada, the correlation is less clear. In the Bay of Fundy, PSP outbreaks appear to be related to long-term tidal fluctuations.

Salmonids in general are naturally susceptible to several viral and bacterial diseases. Until 1975, furunculosis (caused by the bacterium *Aeromonas salmonicida*) had been detected only in British Columbia, Alberta, Ontario and Quebec. In 1975, it was identified in the Restigouche River bordering the provinces of Quebec and New Brunswick. Since then, it has caused mortality in both juvenile and adult salmon in the Restigouche River system.

The seal worm, long endemic in Atlantic seal (the definitive host) spends part of its life cycle in cod where it is also parasitic. The incidence of the worm in cod has reportedly been increasing in recent years, causing declines in the quality of landed cod. Increases in the parasite in cod have been associated with growth in seal populations. One likely explanation of that growth is that it was, surprisingly, an indirect result of a change in the harvesting technique for swordfish.[3]

In the 1960s the hand-harpooning of swordfish was replaced by longlining, a technique that is not species-specific and that resulted in a great number of sharks being caught inadvertently. This led to a significant reduction in the shark population in the northwest Atlantic and, consequently, to an increase in their prey species, including seals. As seals are the definitive host of the seal worm (the worms mature and produce eggs in the host, the eggs are released in seal feces and enter the marine food chain), an increase in the seal population led to increased production of seal worm. As a consequence, there was an increased incidence of seal worm in cod.

Contaminants

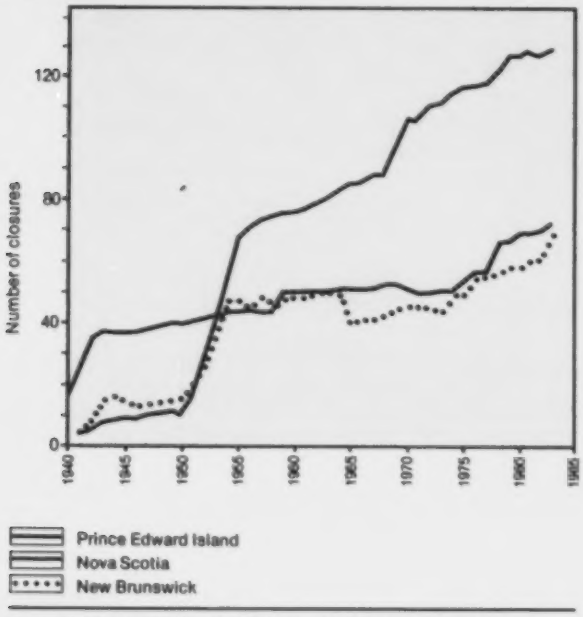
When fecal contamination produces a coliform count exceeding 14 organisms per 100 mL of water, a shellfish area is closed to harvesting. The number of areas closed thus provides an indirect measure of domestic sewage problems in coastal waters. The history of closures is given in Figure 5.23. Since 1940, the number of administrative closures in the Atlantic Maritime region has increased steadily. In 1940, there were 20 closures; in 1984 there were over 250, and some 100 000 hectares of surface area are now closed to shellfish harvesting. It is difficult to determine without data on sewage treatment whether the increased number of closures is due to higher coliform contamination or to the increase in surveillance. (See also Chapter 8.)

MAJOR INFLUENCES ON THE ATLANTIC MARINE ECOSYSTEM

Harvesting

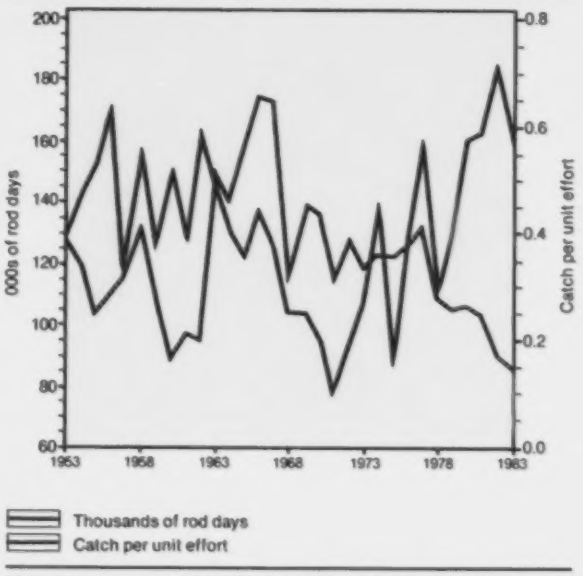
Harvesting pressures have undoubtedly had a major influence on northwest Atlantic fisheries. The importance of harvesting is best seen when pressures decrease and depressed stocks rebound.

Figure 5.23
Shellfish Closures in the Maritime Provinces, 1940-1984



Source: Environment Canada, Environmental Protection Service, Dartmouth, Nova Scotia.

Figure 5.24
Atlantic Salmon Angled Catch, Effort and Catch Per Effort, Maritime Region, 1953-1983



Source: Department of Fisheries and Oceans, Canadian Data Report of Fisheries and Aquatic Sciences, Nos. 258 and 450.

Any discussion of harvesting pressure should be in terms of the amount and type of gear used and the time spent fishing. For the northwest Atlantic region as a whole, such data are unavailable. Proxy variables, such as the number of licensed fishermen, must be treated with great caution.

Over-harvesting of certain valued fisheries has led to sharp declines in commercial catches of major finfish and shellfish, clearly signalling a level of harvesting beyond the stocks' ability to provide sustainable yield. Preliminary data for 1983 indicate that total herring landings (Figure 5.16) are less than 20 per cent of peak 1969-1970 values. Landings of cod (Figure 5.15), the mainstay of the Atlantic fishery, declined to less than 50 per cent of peak 1968 levels. Salmon stocks appear to be on the wane (Figure 5.18), and landings of scallops declined significantly over the seven-year period up to 1983, the most recent period for which data are available (Figure 5.20). Capelin stocks have also declined.

On the positive side, there has been a partial recovery in lobster (Figure 5.19), and haddock stocks also appear to be on the increase. Furthermore, under current fishing regulations, the downward trend in total finfish landings appears to have been arrested, and signs of recovery in important stocks such as cod are beginning to appear.

The best data on harvesting pressure are for the salmon fishery. Even here the data must be interpreted with caution. Table 5.16 provides data on the number of licensed commercial salmon fishermen in the Atlantic provinces. These data do not take into account the fishermen of western Greenland, who take some salmon of Canadian origin, or salmon landed as by-catch (up to 30 per cent of the total catch in some areas).

Table 5.16 nonetheless shows some interesting trends. Until 1970, there were about 9 000 fishermen licensed for salmon fishing, the vast majority (81 per cent) in Newfoundland, followed by New Brunswick (7 per cent), Nova Scotia (6 per cent), Quebec (6 per cent) and P.E.I. (0.1 per cent). From 1972 to 1980, a ban was placed on commercial fishing in New Brunswick and the Gaspé region of Quebec, and the drift-net fishery off Port-aux-Basques in Newfoundland was shut down permanently. In the first year of the ban, the number of fishermen with nets in the water decreased to 5 621 (1972) from 8 010 (1971). Despite the ban, however, the number of fishermen actually increased thereafter, reaching a peak of 7 500 in 1975. This increase was because of new licences issued in Newfoundland. After the ban was lifted in 1981, the total number of licensed fishermen remained more or less constant at about 6 000, 88 per cent of them Newfoundlanders.

Better estimates of fishing pressure are available for the salmon angling fishery. Here, fishing effort is usually expressed in 'rod days' (i.e., one angler fish-

Table 5.16
Number of Active Commercial Salmon Fishermen in the Eastern Canadian Provinces, 1968-1983

	Number of licensed fishermen by province							
	New Brunswick	Nova Scotia	Prince Edward Island	Newfoundland	Quebec	Total	Catch (tonnes)	CUE[3]
1968[1]	634	573	9	7 342	501	9 059	2 119	.23
1969	638	545	9	6 846	501	9 059	1 957	.22
1970	695	522	8	7 919	379	9 523	2 091	.22
1971	723	498	8	6 403	378	8 010	1 839	.23
1972[2]	—	424	7	4 976	214	5 621	1 537	.27
1973	—	404	7	5 050	211	5 672	2 150	.38
1974	—	385	7	5 880	211	6 483	2 245	.35
1975	—	372	7	6 981	211	7 571	2 245	.30
1976	—	367	6	6 259	210	6 842	2 212	.32
1977	—	289	6	5 719	209	6 223	2 151	.35
1978	—	284	6	5 815	210	6 315	1 379	.22
1979	—	282	6	5 768	211	6 267	1 092	.17
1980	—	276	6	5 592	209	6 083	2 384	.39
1981	231	254	6	5 402	228	6 121	2 138	.35
1982	218	229	6	5 071	228	5 752	1 570	.27
1983	214	225	6	5 176	258	5 879	1 500	.25

[1]Number of fishermen listed for 1968, 1969 and 1970 are best estimates and not as accurate as recorded for later years.
[2]Commercial ban introduced, which kept all New Brunswick nets out of the water as well as nets in the Gaspé, Quebec and Port aux Basques, Newfoundland for the period 1972-1980.
[3]Catch per unit effort.
Source: Anderson Consultants Incorporated, St. Andrews, N.B., report submitted to Statistics Canada, January 1984, based on data from Department of Fisheries and Oceans.

ing for one day = one rod day of effort). Based on this measure, fishing pressure on angled salmon in Nova Scotia, Prince Edward Island and New Brunswick fluctuated widely over the period between 1953 and 1983. For most years, however, the range was between 125 000 and 183 000 rod days. The catch per unit effort fluctuated between 0.06 (1967) and 0.115 (1983), again rather randomly, although the last six years (1978-1983) show relatively low values (Figure 5.24).

The picture for Newfoundland and Labrador is given in Figure 5.25. Fishing pressure more than tripled between 1953 and 1982. The catch per unit effort rose from 0.37 in 1953 to 0.50 in 1965, but then declined, reaching a new low in 1978. The percentage of grilse* rose from 84 per cent in 1953 to 96-97 per cent of the catch in recent years. Thus is would appear the trend has been that fishermen wait longer and catch smaller fish.

*Atlantic salmon grilse (generally males) return to their natal streams after only one year at sea. For statistical purposes, these are salmon under 2.7 kg.

Pollution

Although the oceans have immense assimilative capacity and there are increasing numbers of observations of oil slicks in the open ocean, pollution is of particular concern in physically confined maritime environments such as inland seas, coastal zones, estuaries and straits. The sources of pollution are either local (municipal sewage, industrial waste disposal, transportation spills) or long-range. Long-range pollution can be atmospheric or waterborne; the latter includes major river outflows. In the Atlantic marine ecosystem, prevailing westerly winds and the St. Lawrence River contribute pollutants from the North American industrial heartland.

In 1975, the St. Lawrence River and estuary showed low levels of contamination.[24] In particular, the river seems not to be a major source of contamination by either oil or trace metals, possibly because the vigorous outflow of surface water flushes them out quickly. In general, the concentrations of most trace metals and oils are not significantly different from

values found in seawater in the open ocean. Local exceptions for petroleum hydrocarbon concentrations occur in the vicinity of shipwrecks. Also of considerable concern in the estuary region are high concentrations of mercury in sediments. These have been traced to sources from industrial plants on the Saguenay River system.[8] (See also Chapter 8.)

Acid rain has had considerable effects on the salmon breeding habitat of coastal rivers, which lack natural buffering capacity. The worst affected areas are in southeastern Nova Scotia. Nine of these rivers no longer suppport salmon because of high levels of acidity (pH less than 4.7).* Other rivers in a pH range of 4.7 to 5.0 have greatly reduced salmon runs. The situation appears to be worsening (see Chapter 8).

Physical Restructuring

Since the mid-nineteenth century, increasing use has been made of the drainage areas of the Gulf of St. Lawrence. Of particular note are two recent large hydro-electric construction projects in the north shore drainage basin, which, because of their reservoir capacity and hydro-dynamics, have increased winter discharge flows and reduced those in spring. (The ratio of spring to winter runoff has changed from 3:1 to approximately 3:2.) This has important consequences for biological productivity.[15] High flow rates promote primary and secondary productivity, while low flow rates reduce productivity.

The seasonality also affects these rates, productivity being dormant in winter and high in the spring and summer. A study of the size of commercial landings of several species on the north shore of the estuary suggests a positive relationship between discharge quantity and species size — this was particularly notable for lobster.[22] When landings were compared with annual river flow nine years earlier (the approximate time it takes for lobsters to reach average catchable age), there was a close correlation between annual lobster landings in Quebec and the April discharge of the river.

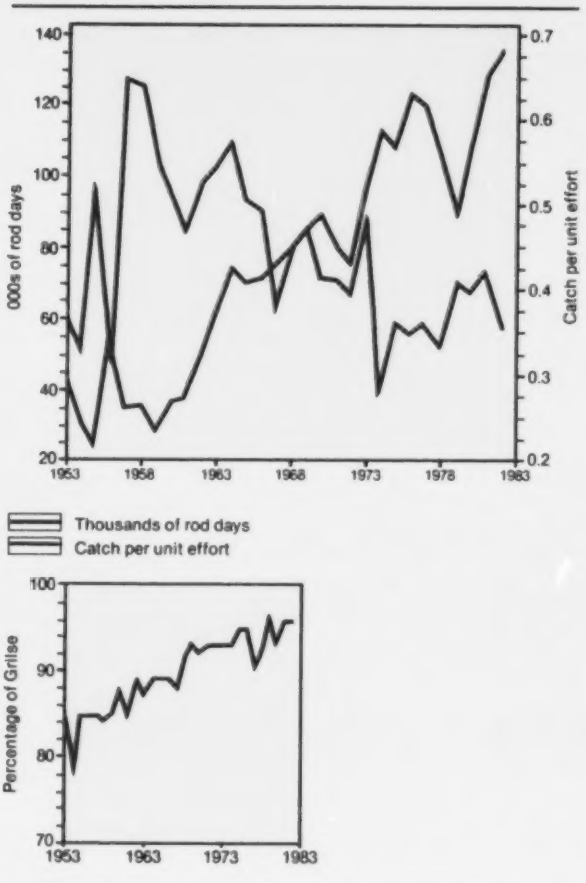
Introduction of Exotics

Exotic species can alter ecosystems in unpredictable ways. If the exotic becomes established, native species are often displaced, and the biotic community can be altered in ways difficult to forecast. Here we report on some evidence of invasions of exotic fishes into Atlantic coastal waters.

The rainbow trout was introduced late in the nineteenth century from its native habitat, the coastal and inland waters of British Columbia and Alberta. While still considered exotic in the eastern provinces, it has now established self-sustaining populations. In the Atlantic provinces, some sea-going runs occur in coastal rivers. Brown trout are also common in Newfoundland, New Brunswick and Nova Scotia. These first appeared in 1884, 1921 and 1923 respectively.

Other salmonid species were introduced more recently into Atlantic Canada. In the late 1950s and early 1960s, a concerted effort was made to establish pink salmon in Newfoundland. About 15 million eggs from British Columbia were planted in selected rivers of the southern part of the Avalon Peninsula. These attempts failed. Pink salmon were, however, introduced successfully into Lake Superior, and this large resident population may well serve as a source from which the rivers along the St. Lawrence and the Gulf might eventually be colonized. In 1983, a pink salmon was caught in the Miramichi River in New Brunswick. Similarly, some migration from the Great

Figure 5.25
Atlantic Salmon Angled Catch, Effort and Catch Per Effort, and Percentage of Grilse, Newfoundland and Labrador, 1953-1982



Source: Department of Fisheries and Oceans, Canadian Data Report of Fisheries and Aquatic Sciences, Nos. 258 and 450.

*These include the Tangier, East, Salmon, Tusket, Clyde, Roseway and Sable Rivers.

Lakes to the Atlantic may be expected for chinook and coho salmon (transplanted from the Pacific).

Coho salmon, recently introduced in the New England states, have been found in the rivers of New Brunswick and Nova Scotia. How these introductions might affect native Atlantic salmon stocks is unknown at present.

Climate Change

Climate variability and change strongly influence the productivity of marine environments. Long records of surface water temperature for the North Atlantic are available. Year-to-year fluctuations in surface temperature have been correlated with commercial landings of some major species. For example, commercial landings for 17 species in the Gulf of Maine have been related to sea-surface temperatures over the 40-year period from 1924 to 1964. From 1924 to the late 1940s and early 1950s there was a gradual warming trend of about 2.5°C, followed by a cooling trend of about 2°C until 1964. Of the 17 species, 10 showed statistically significant correlations with these temperature changes. In some cases (e.g., herring) higher temperatures were accompanied by higher yields; in other cases, catches declined at higher temperatures.[23]

ASSESSMENT

The condition of the Canadian Atlantic marine ecosystem is moulded by at least four major forces: short-term climatic change reflected in changes in the temperature of surface waters; harvesting of major stocks of finfish and shellfish; pollution (e.g., acidification of rivers in eastern Nova Scotia and the presence of sewage in coastal shellfish areas); and changes in the hydrological regime of major rivers on a scale sufficient to affect the hydrology and nutrient processes of the entire St. Lawrence estuary.

These influences, separately and interactively, have altered marine ecosystems and associated freshwater streams and estuaries in significant ways. The acidification of a number of Nova Scotia salmon spawning rivers has resulted in the loss of salmon runs in nine rivers, and steady declines in the pH values of many more threaten still further runs. Acid precipitation has produced environmental change in these sensitive systems that is unlikely to be reversed. Indeed, the prospect for the immediate future is that more rivers (and lakes) are likely to lose their life-supporting capabilities.

Over-harvesting of certain valued fisheries has led to sharp declines in commercial catches of major finfish and shellfish stocks, signalling clearly a level of harvesting beyond the stocks' capability to provide sustainable yield. Preliminary data for 1983 indicate total herring landings are less than 20 per cent of peak 1969-1970 values. Landings of cod, the mainstay of the Atlantic fishery, declined to less than 50 per cent of peak 1968 levels. Salmon stocks appear to be on the wane, and landings of scallops declined significantly over the 7-year period up to 1983 (the most recent year for which data are available). Capelin stocks have also declined.

On the positive side, there has been a partial recovery in lobster, and haddock stocks also appear to be on the increase. Further, under current fishing regulations, the downward trend in total finfish landings appears to have been arrested, and signs of recovery in important stocks such as cod are beginning to appear.

The presence of sewage in coastal waters and estuaries has led to closures of shellfish harvesting areas as a health precaution. The increase in closures since 1940 may reflect an increase in the number of areas surveyed as well as the spread of sewage. Nonetheless, it is significant that by 1983, more than 40 years after the problem was recognized, over 250 shellfish closures were in effect, closing over 100 000 hectares to commercial shellfish harvesting as a result of unacceptable coliform levels. Municipal sewage and fish plant wastes account for most point-source closures, while private sewage disposal and storm runoff account for most non-point sources.

Increased sewage flow into coastal marine systems might well result in increasing primary productivity. Unfortunately, the long-term studies required to determine whether this is, indeed, the case are lacking.

Are the biota of the Atlantic marine system altering their size spectrum characteristics in response to various pressures? For some commercially fished stocks, such as herring and lobster, fishing pressure has led to reductions in average age (size). In other stocks (e.g., haddock), especially those reduced in abundance as a result of previous harvesting, survivors are growing larger at an earlier age owing to reduced competition for food supplies. While data are available for some individual stocks, data are insufficient to determine the size-spectrum characteristics of the Atlantic fish community as a whole.

Diseases in the Atlantic marine system include blooms of *Gonyaulax*, causing shellfish to become toxic (which can cause fatalities in humans as a result of paralytic shellfish poisoning). There are suggestions that the incidence of *Gonyaulax* blooms is increasing and that this might be attributable to more sewage in coastal waters (providing more favourable nutrient conditions for the organism). Long-term tidal fluctuations are also thought to be an important causal factor. Unfortunately, data on shellfish closures alone do not provide direct information on the frequency and extensiveness of *Gonyaulax* blooms.

The seal worm, long endemic in Atlantic seal (the definitive host) spends part of its life cycle in cod where it is also parasitic. The incidence of the worm in cod has reportedly been increasing in recent years, causing declines in the quality of the cod fishery.

Increases in the parasite in cod have been associated with increases in seal populations.

Among the new diseases emerging in Atlantic coastal river waters, furunculosis, a bacterial disease affecting salmonids, appears to be spreading from Ontario and Quebec into eastern waters. It is now present in the Restigouche River, where it has caused mortality in both juvenile and adult salmon.

An important force shaping the St. Lawrence estuary and Gulf ecosystem may be the large-scale hydro-electric developments in the north shore basins. These mega-projects have altered the ratio of spring to winter runoff. Changes in the hydrological regime affect the nutrient supply to the Gulf, primary productivity and, through a variety of interactions, the abundance of biota in the Gulf (e.g., lobster).

Climate change has resulted in alternating periods of warmer and cooler surface waters, with variations in the neighbourhood of 2 to 3°C in some areas (e.g., the Gulf of Maine). Such changes have apparently had significant effects on the abundance of some species (e.g., warmer waters favouring herring and cooler waters favouring cod in the Gulf of Maine).

In summary, the Atlantic marine ecosystem has been affected in recent decades by natural disturbance (short-term climate changes) and a host of human influences (particularly hydro-electric development, harvesting and local sewage disposal). Important stocks of fish have declined; certain salmonid streams are no longer viable; and there may be an increasing incidence of diseases related to human intervention. With respect to hydro-electric development and pollution there are few signs of corrective change. With respect to harvesting, fisheries are becoming better regulated and, as a result, there are indications that some of the valued commercial stocks are responding positively to reduced harvesting pressure and are beginning to recover.

PACIFIC MARINE ECOSYSTEM

INTRODUCTION

This discussion of the Pacific marine ecosystem is divided into four parts. The first serves as an introduction to the oceanography and geography of the region. The second describes conditions and trends in the Pacific marine environment. The third provides a description of the major influences on the Pacific marine system, human and climatic. The concluding part provides a qualitative assessment of the Pacific marine environment, drawing attention to the major environmental trends and their probable causes.

Several oceanographic features of the British Columbia coast bear description at the outset, as they have considerable influence on the regional maritime environment.[15]

Continental shelves make up approximately 5 per cent of the Pacific marine zone and support highly productive fisheries. The British Columbian shelf is narrow — typically less than 45 kilometres (km) wide and rarely more than 95 km wide. (By comparison, the shelf off Nova Scotia generally exceeds 185 km in width.) Landward of the shelf, there is a complex of inlets, straits, passes, sounds and narrows, along with hundreds of islands. From the coastal mountains, numerous rivers empty into the ocean. The larger rivers (e.g., the Fraser) are big enough to influence the current in the entire passage from the entrance of the Strait of Juan de Fuca to Queen Charlotte Sound. Indeed, the entire passage from the entrance to the Strait of Juan de Fuca to the entrance of Queen Charlotte Strait might be considered part of the Fraser River estuary.

The estuaries act as nutrient traps, collecting river-borne organic and inorganic materials and concentrating them in sediments. This provides an enriched energy supply to support large populations of marine life and associated waterfowl.

Sills are among the most important features of British Columbia coastal waterways. These are underwater ridges, deposited by glaciers, that cause the entrances to most inlets and some important straits (e.g., Georgia and Juan de Fuca) to be relatively shallow. The lack of depth tends to inhibit the passage of oxygenated seawater into inlets. Thus, water in the sheltered deep inlets may become depleted of oxygen. Bottom waters in Powell Lake exhibit anoxia throughout the year, while Saanich Inlet, Nitinat Lake and Hood Canal in Puget Sound exhibit anoxia in bottom waters during part of the year.

Water temperatures vary widely. In winter, typical sea-surface temperatures vary from about 8°C off Vancouver Island to 6°C off the Alaska panhandle. With spring and summer warming, there is a substantial increase in surface temperatures — by late August, the top layer of the water off Vancouver Island is at 15 to 18°C and may be as high as 20°C. Large

variability has been recorded from year to year. In the summer of 1957, exceptionally high surface temperatures (20°C) were common along the coast. In contrast there were abnormally low surface temperatures in 1971.

These various oceanographic features have considerable influence on the biological communities of the British Columbia coastal environment. Oysters, for example, require warm water with little temperature variation and a water circulation pattern that does not sweep floating larvae out of the protection of the embayment. These conditions are met in Pendrell Sound, a major oyster spawning area.

On socio-economic grounds the British Columbia coast can be subdivided into three major regions: south, central and north. The south coast (the Strait of Georgia and the landward part of Vancouver Island) is heavily populated and dominated by the Fraser River and its estuary. The central coast, flanked by rugged coastal mountains, is thinly populated. The north coast, while sparse in population, is a region of large-scale forestry and mining activity. For purposes of this report, we consider the region as a whole, although some data are more conveniently presented in terms of the subdivisions just mentioned.

STATE OF THE PACIFIC MARINE ECOSYSTEM

In recent years, environmental concerns about Canada's Pacific marine ecosystem have centred on declines in valued fisheries (particularly salmon), increased sewage pollution in coastal areas, the loss of fish and wildlife habitats as a result of the drainage of wetlands for agricultural purposes, the use of estuaries for log storage, and the effects of forestry and hydro-electric projects. At the same time, most people believe that British Columbia's marine environment is comparatively clean and that major changes are as likely to be attributable to natural causes as to human intervention.

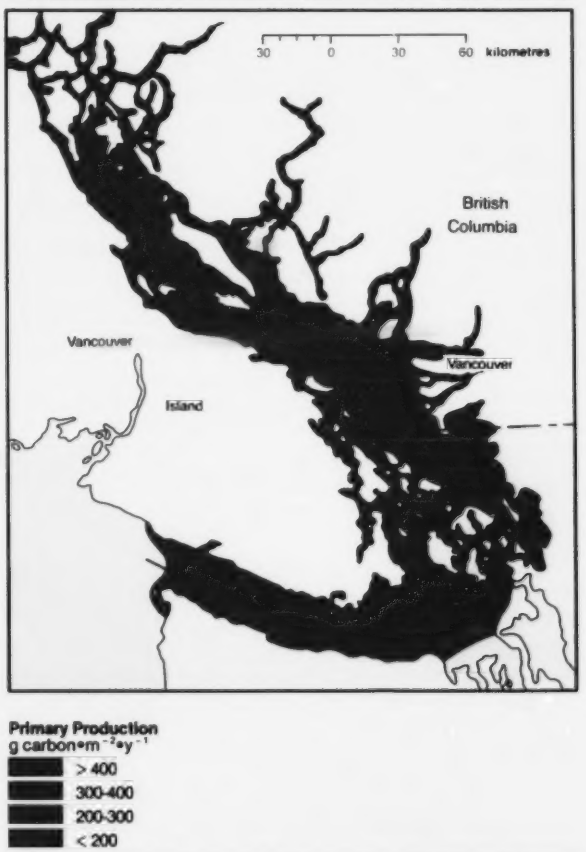
There is a scarcity of long-term data on indicators of the state of the Pacific marine ecosystem. Most studies are not only restricted to specific regions (a single estuary, for example) but are also short-term, with little or no follow-up. Given these limitations, discussion will be limited to the following: (a) primary productivity (from special studies of conditions in the Strait of Georgia and satellite photos of phytoplankton distribution around the Queen Charlotte Islands and Vancouver Island); (b) the abundance of fish stocks and marine mammals; (c) the biotic size spectrum within several salmon stocks; (d) disease incidence (paralytic shellfish poisoning and furunculosis); and (e) contaminants and sewage (from data on coliform counts leading to shellfish harvest closures; concentration of contaminants in Fraser River and estuarine biota and sediments).

Primary Productivity

Primary productivity is the base of the food chain for marine systems. Fundamental shifts in productivity signal environmental change with ramifications throughout the entire ecosystem. It would be ideal to have long-term studies of major regions of the British Columbia coast as a basis for assessing environmental change. Unfortunately, such data are not available. The findings of a recent review of productivity for the Strait of Georgia[9] and available satellite images convey the spatial variability in primary productivity of the Pacific marine ecosystem. These data may serve as a baseline for later comparisons.

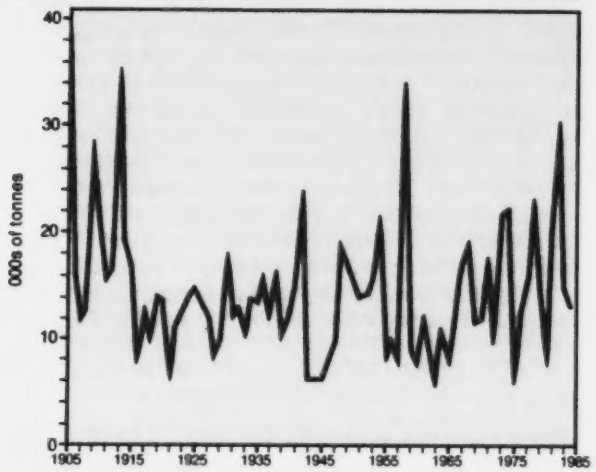
The spatial variability in primary productivity in the Strait of Georgia is shown in Figure 5.26. Produc-

Figure 5.26
Spatial Variability in Primary Productivity in the Strait of Georgia



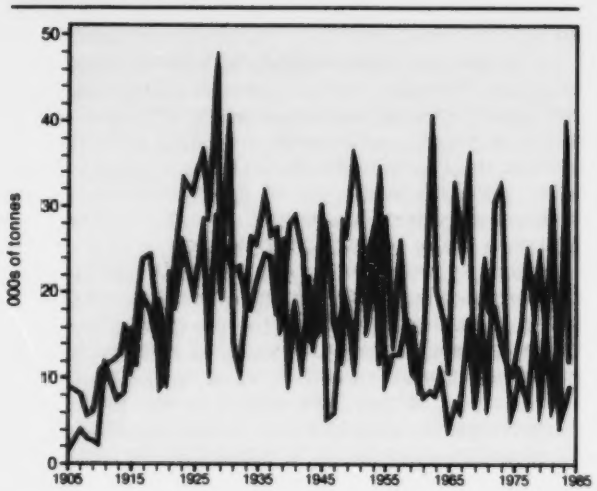
Source: J.G. Stockner, et al., "Phytoplankton Ecology of the Strait of Georgia, British Columbia", *Journal of the Fisheries Research Board of Canada* 36(1979): 657-666.

Figure 5.27
Canadian Commercial Landings of Sockeye Salmon, 1905-1984



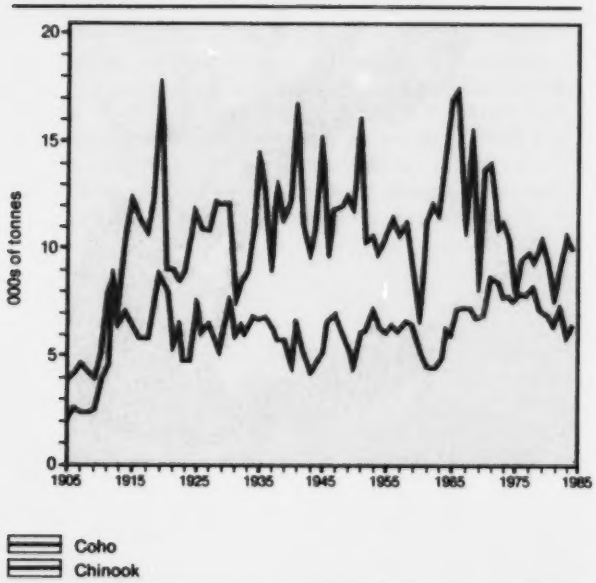
Source: Department of Fisheries and Oceans, Fisheries Research Branch, unpublished data.

Figure 5.28
Canadian Commercial Landings of Chum and Pink Salmon, 1905-1984



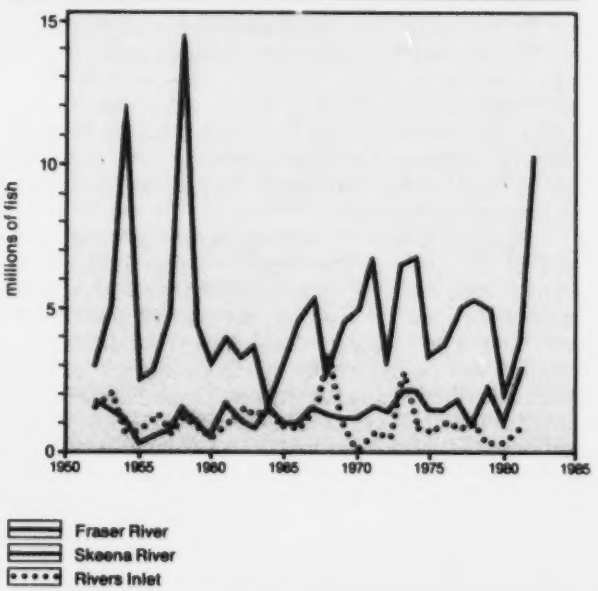
Source: Department of Fisheries and Oceans, Fisheries Research Branch, unpublished data.

Figure 5.29
Canadian Commercial Landings of Coho and Chinook Salmon, 1905-1984



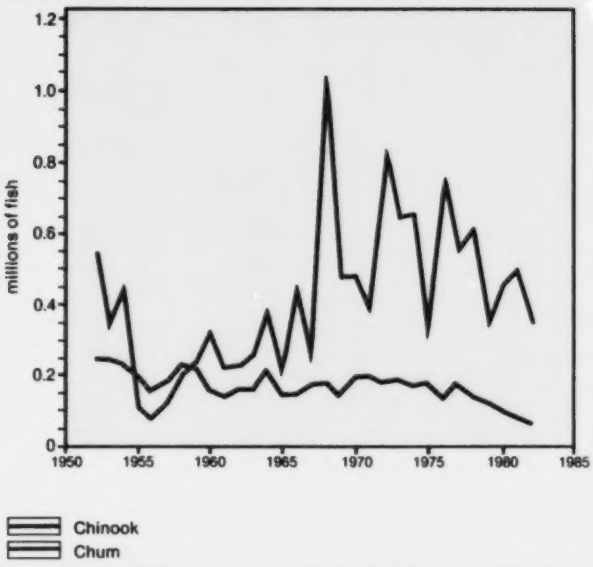
Source: Department of Fisheries and Oceans, Fisheries Research Branch, unpublished data.

Figure 5.30
Estimated Sockeye Salmon Stocks from the Fraser and Skeena Rivers and Rivers Inlet, 1952-1982



Source: Department of Fisheries and Oceans, Pacific Biological Station, Nanaimo, unpublished data.

Figure 5.31
Estimated Chinook and Chum Salmon Stocks[1] from the Fraser River, 1952-1982



[1] Stock estimate is the sum of escapement plus catch.
Source: Department of Fisheries and Oceans, Pacific Biological Station, Nanaimo, unpublished data.

tivity exceeds 400 grams of carbon per square metre per year (gC/m^2/y) in most coastal areas, especially those near urban or industrial centres. Productivity is below 200 gC/m^2/y in the extreme south of the Strait. For the open waters north of this zone, productivity ranges between 200 and 300 gC/m^2/y. Seasonally, primary productivity in this region begins to increase in February, reaching a maximum of 1.28 gC/m^2/day in May and subsequently declining to 0.28 gC/m^2/day in later summer.[7] Estimates of annual primary productivity for the Strait of Georgia[11,14] range between 120 gC/m^2/y and 345 gC/m^2/y. These differences arise in part from different methods of sampling. A recent review concluded that the average value for primary productivity in the Strait was 275 gC/m^2/y.[9]

Additional information on algal productivity off the west coast of Canada has been determined from images obtained from the Nimbus 7 satellite. For example, mesoscale eddies (on a scale of 80 km) to the west of the Queen Charlotte Islands have been sited in clear oceanic water with productivity (measured as chlorophyll pigment) higher than background levels. Mesoscale eddies take 10 days to deform appreciably, while inshore oceanic features are probably created and destroyed within 5 to 10 days.

Productivity values obtained from satellite images of the waters surrounding Vancouver Island are typical and confirm values obtained from observations from ships. Wind-driven upwellings are easily locatable, and plumes of highly pigmented water are clearly visible on satellite images. These plumes, which are characteristic of the waters off Vancouver Island, have a life span of about a week.

Abundance of Fish and Marine Mammals

Changes in the abundance of major species in the Pacific marine ecosystem may reflect significant environmental changes from a variety of influences. This section examines trends in the three major fisheries (salmon, herring and halibut), as well as trends in the major marine mammal populations, including stellar sea lions, California sea lions, and killer whales.

Five species of salmon are indigenous to the coastal waters of British Columbia. Chinook, the largest, most highly prized game fish, live from 3 to 7 years and weigh up to 30 kg. Coho usually live 3 years and weigh up to 14 kg. Sockeye, almost toothless, and the most streamlined of the Pacific species, live from 4 to 5 years and generally weigh 2 to 3 kg. Chum look like sockeye but are larger, averaging around 4 kg. Pink, the smallest of the Pacific salmon, live only 2 years and generally weigh less than 2 kg.

Trends in commercial landings of Canadian salmon for the period 1905-1984 are given in Figures 5.27 to 5.29. Landings of all stocks have shown considerable variation over time. The commercial catch of sockeye has fluctuated between 6 000 and 35 000 tonnes (Figure 5.27) with no distinct trend, although 3 of the 4 peak landings were in the early years. Landings of pink salmon have fluctuated widely, with no distinct trend since the fishery began (1905-1917). Since 1950, there has been a downward tendency in chum landings, although there was a sharp rebound during the early 1970s. Coho and chinook catches appear to show an upward trend over the period. These data refer to Canadian landings of all salmon, regardless of origin, including fish of American origin caught by Canadian fishermen. However, chinook stocks of Canadian origin are currently in poor shape; this is not reflected in these data, which include fish from hatcheries and rivers in the United States (especially the salmonid enhancement programs on the Columbia River).

Looking more closely at individual stocks for major river systems for which relatively reliable escapement data are available, Figure 5.30 shows recent trends for three major sockeye runs: the Fraser River, the Skeena River, and Rivers Inlet. In each case marked fluctuations occurred. Total production (i.e., escapement plus catch) exhibits no clear trend.

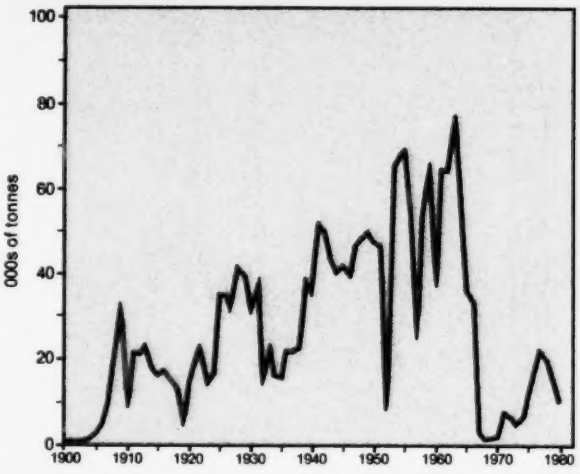
Concern has been focused on certain stocks that have shown declines in recent decades. These stocks include chinook in the Fraser River and the Strait of Georgia, sockeye in the central coast and Rivers-Smith Inlet, and chum in most areas. Figure 5.31 shows

Table 5.17
British Columbia Roe Herring Fishery, Landings and Landed Value, 1972-1984

	Landed Weight (tonnes)	Landed Value ($000)
1972	34 596	2 261
1973	50 980	10 523
1974	43 505	11 876
1975	53 278	13 712
1976	78 776	22 736
1977	73 369	28 135
1978	63 255	50 412
1979	37 284	121 855
1980	16 246	23 909
1981	29 300	32 620
1982	27 481	31 579
1983	38 869	46 085
1984	32 623	42 427

Excludes spawn on kelp landings and values.
Source: Department of Fisheries and Oceans, *Fisheries Statistics of British Columbia* (Vancouver: various years).

Figure 5.32
Historical Production of Herring by the Canadian Fishery in the Strait of Georgia, 1900-1980



Source: K.S. Ketchen et al., "History and present status of fisheries for marine fishes and invertebrates in the Strait of Georgia, British Columbia", *Canadian Journal of Fisheries and Aquatic Sciences* 40/7 (1983): 1095-1119.

Table 5.18
Comparison of Mean Weight of Landed Catch of British Columbia Salmon, 1951 and 1975
(kilograms)

Species	1951	1975	% Change
Pink[1]	2.5	2.0	-20.0
Pink[2]	2.1	1.4	-34.0
Chum — G	5.3	4.9	-7.6
Chum — S	5.7	5.0	-12.3
Sockeye — G	2.8	2.7	-3.6
Sockeye — S	2.7	2.5	-7.4
Sockeye — T	3.0	2.8	-6.7
Coho — G	4.4	3.5	-21.5
Coho — S	4.2	3.2	-23.8
Coho — T	3.8	2.8	-26.3
Chinook — T	7.6	5.1	-32.7

T troll fishing
S seine fishing
G gillnet fishing
[1] Odd-year pink, years covered 1952 and 1974.
[2] Even-year pink, years covered 1952 and 1974.
Source: Calculated from W.E. Ricker, "Changes in the Average Size and Average Weight of Pacific Salmon", *Canadian Journal of Fisheries and Aquatic Sciences* 38 (1981): 1636-1656.

recent trends in the chinook and chum stocks of the Fraser River. Although there is a clear downward trend in chum, there is no change with respect to chinook.

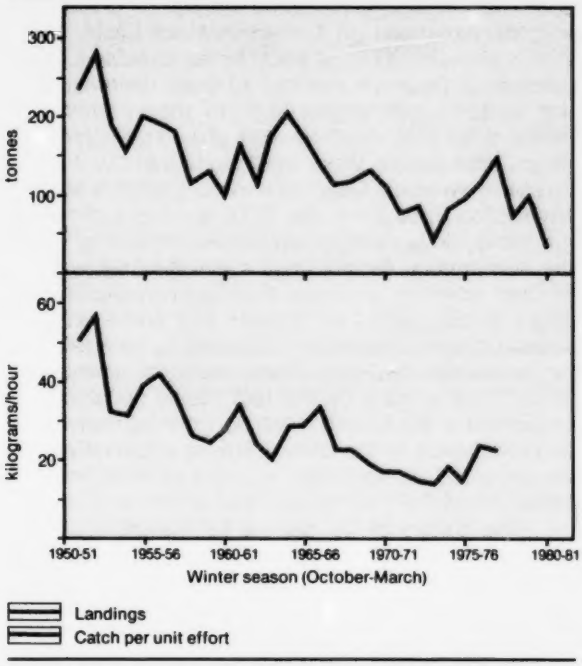
The herring fishery is the second most important fishery on the Pacific coast. The fishery developed early in this century, with the discovery of a market for dry salted herring in the Orient. Fluctuations in the catch characterized the fishery throughout its history and were strongly influenced by both market conditions and fish stock collapse. In the 1920s, the annual catch rose to a high of 77 000 tonnes, then plummeted to 27 000 tonnes during the Depression. The historical production of herring in the Strait of Georgia fishery (shown in Figure 5.32) follows these trends.

With the development of secondary herring industries (processing herring for meal and oil), catches increased sharply and averaged around 181 000 tonnes annually during the 1950s. Catches in the early 1960s were even larger, reaching a peak at 240 000 tonnes in the 1962-63 season. With the collapse of stocks in the mid-1960s, the fishery was closed for some time.

In the 1970s, as herring stocks began to recover, a market for herring roe opened up in Japan, and heavy commercial fishing pressure on herring stocks resumed. The landings are characterized by a series of sharp peaks and declines (Table 5.17).

Halibut is the third most important west coast fishery. Landings by Canadian and United States fishermen peaked in the 1920s at 31.8 million tonnes

Figure 5.33
Canadian Landings of English Sole from the Strait of Georgia, 1950-1981



Source: K.S. Ketchen et al., "History and present status of fisheries for marine fishes and invertebrates in the Strait of Georgia, British Columbia", *Canadian Journal of Fisheries and Aquatic Sciences* 40/7 (1983): 1095-1119.

and declined to 13.6 million tonnes in the early 1930s. The bilateral International Halibut Commission succeeded in rehabilitating the stocks, and landings rose to 34 million tonnes by 1962. Stocks have since declined again, and total landings in both countries now range between 9 million and 14 million tonnes.

In addition to the important commercial species already discussed, English sole merits special attention as there are suggestions that this species has been affected by pollution of the inner and subtidal habitat occupied by young fish.[10] Figure 5.33 shows downward trends in Canadian landings of English sole from the Strait of Georgia between 1950 and 1981.

Turning to trends in marine mammals in British Columbia waters, resident populations of sea lions and killer whales form an important component. A review of data on the number of stellar sea lions (*Eumetopias jubatus*) sighted or killed in British Columbia waters since 1913 has recently been completed.[2] At least 14 000 animals of all ages were counted in 1913. Kills between 1913 and 1968 resulted in a series of population declines. Between 1971 and 1982, numbers averaged 3 800 on rockeries and 1 900 on year-round haulouts.

The California sea lion has increased in recent years in B.C. waters. This species was rare in these waters (at least between the late 1800s and the 1960s) and was confined to waters off southwestern Vancouver Island. In the 1970s the species expanded into waters off southeastern Vancouver Island as the population increased from about 500 animals in 1972 to 4 500 in 1984, with most of the increase taking place since 1980.

Killer whales in British Columbia waters also appear to have been increasing slowly over the last decade. An estimated 261 are now year-round residents of waters in the vicinity of Vancouver Island. The whales are grouped into about 30 pods. The population growth in recent years is estimated to be between 2 and 2.5 per cent per annum.[1]

Biotic Size

The best data on changes in the size of biota are for salmon. Fishing practices generally select the large, older individuals. Records for the five B.C. salmon species show declines in weight for all species.[12] The average size of chinook salmon appears to have decreased since the 1920s. Since the 1950s, other species have decreased in size, particularly the cohos and pinks; chum and sockeye have shown less of a decline. Between 1957 and 1972, the mean age of chum increased, although the overall size still declined. Data showing decreases in the mean weight of the B.C. salmon catch are in Table 5.18. Reductions in the size of herring (not shown) have also occurred with the removal of older larger fish.

Diseases

Pacific shellfish, like Atlantic species, are host to the marine plankton organism, *Gonyaulax excavata*. There have been regular outbreaks of *Gonyaulax* infection along the outer coast; as a result, these areas are closed permanently to recreational shellfish harvesting. Portions of Johnstone Strait and the Strait of Georgia are closed periodically to shellfish harvesting because of known or suspected cases of paralytic shellfish poisoning (PSP). Temporary closures appear to have become more frequent in recent years.

Current monitoring for PSP has some serious drawbacks. First, monitoring is concentrated on commercial shellfish; few non-commercial beaches are monitored unless there is a suspected outbreak of PSP. Second, shellfish poisoning may be confused with a milder disease causing flu-like symptoms. When there are reports of the latter, beaches are invariably closed without firm evidence that the cause of the illness was PSP. Direct monitoring of the syphons of butterclams and other molluscs for concentrations of the toxins producing PSP would result in better information on infestation instead of relying on data on areas under closure.

Contaminants

British Columbia's offshore waters seem to be relatively free of pollution because contaminants are quickly dispersed. Concentrations of trace metals and selected organic contaminants in Fraser River fish are relatively low.[13] Comparable concentrations of arsenic, cadmium, iron, manganese and zinc were found in fish from upstream (industry-free areas) and the lower Fraser (highly industralized). While lead, magnesium and mercury are higher in tissues from fish of the industrialized lower Fraser, mercury was less than the 0.5 mg/kg tolerance level for human consumption. A comparison with data gathered a decade ago suggests that the situation has improved. The lower Fraser River fish collected in 1972-73 had higher levels of copper, lead, manganese, mercury and zinc than samples collected 10 years later.[13]

A comparison of organic contaminants in sediments and fish taken from the Fraser River estuary showed that the highest levels were in fish and sediments from the freshwater slough adjacent to a major landfill and to three stations in the North Arm of the Fraser that receive waste from industry, the city of Vancouver, and a major sewage treatment plant.[7] Fish tissue (starry flounder) contained relatively high levels of several chlorinated phenols. Concentrations of these contaminants were usually higher close to the landfill site and the sewage treatment plants in the estuary.

The closure of shellfish harvesting because of high coliform counts in the water serves as an index of sewage contamination in British Columbia's coastal marine waters. Other factors are also considered in determining the area to be closed. These include the discharge characteristics of nearby effluents (volume, quality and periodicity), the influence of rainfall and resultant runoff effects, the occurrence of transient pollution sources (e.g., vessels) and so forth.

As shown in Table 5.19, the number of closures almost tripled from 1972 to 1983, while the coastline under closure increased from 464.9 km to 678 km and the area increased from 51 655 ha to 54 187 ha. This last figure may indicate a slight increase in contamination of coastal waters from sewage over the past decade, but it could also reflect an increase in the areas surveyed.

MAJOR INFLUENCES ON THE PACIFIC MARINE ECOSYSTEM

Changes in the state of the Pacific marine ecosystem are obviously the result of a number of influences, and the joint effects of various stresses may be more than the sum of the parts.

The main influences on conditions in the Pacific marine and coastal environment appear to be harvesting, physical restructuring, pollution, and climatic change.

Harvesting

Harvesting pressure has undoubtedly led to some decreases in Pacific salmonid stocks. When salmon data are examined on a stock-by-stock basis, some stocks show evidence of declines attributable to overharvesting. Sockeye stocks had been decreasing in the central coast region (e.g., in the Rivers-Smith Inlets). After strict controls were placed on fishing for Rivers Inlet stocks, there were signs that the decline had been reversed. Chum salmon exhibited a persistent decline throughout the 1950s and the first half of the 1960s, likely owing to excessive harvesting. When the commercial fishery on the south coast was restricted severely to allow increased escapements, chum stocks began to recover. For some chinook salmon stocks, over-fishing appears to be contributing to current declines. These declines are masked in the landing data by the fact that a considerable proportion of the landed catch now comes from rivers and hatcheries in the United States, especially from the salmonid enhancement projects on the Columbia River.

The history of the herring fishery provides one of the clearest examples of the dramatic impact fishing can have on stocks. In the mid-1960s, when heavy fishing pressure coincided with weak recruitment, the stocks collapsed. When fishing was restricted, the stocks recovered remarkably.

With respect to halibut, it is believed that heavy by-catches of halibut by Russian and Japanese trawlers harvesting other groundfish were the main cause of the sharp decline in halibut stocks.[5]

Physical Restructuring

Dams and Water Diversions

Along many important river systems in British Columbia, dams and diversions for hydro-electric power generation and other purposes have had a considerable impact on the habitat for salmon and other anadromous stocks. Some of the most conspicuous and devastating effects have come about from landslides into spawning rivers. The Hell's Gate slides of 1913 and 1914 on the Fraser River (caused by the deliberate dumping of rock from railroad construction into the river) had serious effects on sockeye and pink stocks by blocking access to spawning beds when water levels were low (usually in the early and mid-season). A natural landslide on the Babine River in 1951 drastically reduced sockeye runs. The risk of slides at both locations has now been reduced by corrective measures.

On the Adams and the Quesnel Rivers, dams (now demolished) contributed at one point to declines in Fraser River salmon stocks. A large number of B.C. rivers have been dammed. In some cases, the dams were built at naturally insurmountable waterfalls and added no new obstruction. Others have fishways,

Table 5.19
Restrictions on Commercial Shellfish Harvest, British Columbia, 1972-1983

	Number of Closures	Coastline Closed (kilometres)	Area Closed (hectares)
1972	40	464.9	51 655.0
1976	57	522.7	53 425.9
1977	66	543.9	54 305.1
1978	75	557.9	54 021.2
1979	81	626.7	51 692.0
1981	89	584.3	52 462.8
1983	118	678.0	54 187.0

Source: Personal Communication, Bruce Kay, Senior Microbiologist, Municipal and Shellfish Projects, Environment Canada, Vancouver, 1984.

Table 5.20
Area Allocated to Log Storage on the South Coast of British Columbia[1]

Estuary	Area (hectares)
Squamish	65.2
Nanaimo	276.5
Fraser[2]	425.5

[1]Including areas set aside for log handling, booming and dumping.
[2]Log storage is 46 per cent of the total area leased.
Source: Canada-British Columbia Fraser River Estuary Study Steering Committee, *Fraser River Estuary Study* (Victoria: 1978).
Canada-British Columbia, Habitat Protection Division, "Habitat Work Group Final Report. Squamish Estuary Management Plan" (1981).
Department of Fisheries and Oceans, Nanaimo Estuary Fish Habitat and Log Management Task Force, "Report of the Log Management Sub-committee to the Steering Committee" (Victoria: 1980).

spawning channels and hatcheries. In several cases of damming, and in water diversions, the damage to fish stocks results from a decrease in the water level below the structure.

Steep Slope Logging

Steep slope logging of British Columbia coastal forests destabilizes the soils, increasing sediment loading in salmon-bearing streams. There is concern on the part of both forest companies and fisheries managers about the potential consequences of such practices. A detailed study of Carnation Creek (on the east coast of Vancouver Island) was undertaken as part of recent efforts to gain a better understanding of the effect of logging on fisheries in order to mitigate adverse effects.[8] The Carnation Creek study showed that, at least in the short run, habitat alterations from clearcutting can be beneficial to salmonids. Smolt production in the initial logging years (1976-1980) was considerably higher than in the pre-logging years (1971-75). The explanation appears to be that tree removal, coupled with mild winters, increased summer stream temperatures by several degrees, increased stream productivity, and increased the growth of resident fry as well as the over-winter survival of under-yearling coho. Ultimately, these events led to the production of more and larger smolt. Additional data are required before the long-term effects of logging on salmon can be assessed.

Disappearance of Wetlands

Wetland changes for the entire coast are difficult to assess quantitatively. With industrial, agricultural and urban development there has been a steady decline in the amount of sensitive foreshore habitat. Wetlands in rivers and estuaries, especially near urban and industrial developments, are particularly vulnerable to alteration. Estuarine habitat has been used extensively for log storage, especially along the south coast (Table 5.20). Substantial wetland habitat has succumbed to agriculture and urbanization, especially in the estuaries near population centres. Nearly all the estuaries of the extreme south coast (especially Fraser, Cowichan, Squamish and Nanaimo) have been depleted of their wetland habitat to varying degrees.

The lower Fraser estuary, the site of much of British Columbia's industrial activity and population, provides the best documented example of habitat loss. This estuary is the habitat for juvenile salmon and supports the largest population of wintering waterfowl in Canada. It is also the single most important stopover for about a million migrating birds along the Pacific flyway from Siberia to South America. Much of its wetlands were lost or significantly transformed by the turn of the century as a result of various flood control and land reclamation projects. A 1974 assessment showed that 71 per cent (221 ha) of saltmarsh, 29 per cent (628 ha) of tidal freshwater marsh, and 98.7 per cent of other flooded habitat had been lost to various developments in the estuary. As of 1975, there were 71.6 km of sea dykes and 48.1 km of river dykes removing 21 241 ha of wetland in the Fraser River delta municipalities of Delta and Richmond.[6]

Some wetland flora have been transplanted to create new habitats. In the Campbell River estuary, some 27 000 cores of sedge salvaged from a site where a log-sorting facility was being built were transplanted on four gravel islands formerly used for log sorting. Early reports indicate that use of these habitats by fish has been substantial and that the transplanted sedges are hosting invertebrate food (insects) eaten by chinook and chum fry.

Pollution

Contaminants in coastal waters come from industrial, agricultural and urban sources and are often discharged directly into important fish-bearing estuaries

and river systems. Urban and agricultural wastes eventually enter the tributaries and estuaries and have resulted in high fecal bacteria counts in adjacent waters. Industrial contaminants from mining operations and the paper and pulp industry contribute to local pollution of estuaries and coastal zones.

The major sewage treatment plant for Vancouver currently discharges up to 1.5 million cubic metres of waste per day into the Strait of Georgia. The effects of this single plant on the aquatic community of the Fraser estuary and the Strait are widespread.

Pulp mills and paper mills are found throughout the British Columbia coastal area, particularly on the Strait of Georgia and on major river tributaries. Many of the older mills use deep water diffusers, which rapidly dilute toxic effluents. Some mills (Alberni, Prince Rupert) are located in sensitive estuary locations; accordingly, stringent effluent quality requirements have been set for them. Improvement of the Neroutsos Inlet area on Vancouver Island was made possible by upgrading the treatment of pulp mill wastes at Port Alice. More stringent effluent standards and the use of secondary treatment plants have been imposed for pulp mills discharging into the Fraser River system, but local problems persist (e.g., Prince George and Kamloops).

A few major mines on the coast — for example, Amax at Alice Arm and Island Cooper on Rupert Inlet — discharge large volumes of waste material into the marine environment. Mining activity has proliferated in many other regions and, in some areas, acute local problems have developed when pollutants have been implicated in the mortality and contamination of various aquatic species (e.g., the Campbell River area on Vancouver Island and the Coquitlam River-Caroline Mines cyanide spill). Abandoned mines can also pose problems for fisheries resources through the release of toxic metal tailings into rivers when settling ponds overflow after storms.

With respect to the petrochemical industry, increasingly, shipments of potentially hazardous materials travel along rivers and estuaries with the risk of spillage (e.g., there was an ethylene dichloride spill in the North Thompson River).

Landfills also cause concern. They are usually placed in flood plains, and materials leach from them and contribute to the pollution of waterways. In marsh areas, landfills may also directly eliminate habitat.

Climate Variability

As discussed in the introduction, small year-to-year changes in the surface temperature of coastal waters can have a significant effect on aquatic habitat. The causes of temperature change are not well understood. There have been suggestions that some of the warm-water episodes are associated with changes in *El Niño*, a current in the southern hemisphere, which in turn have been related to a breakdown of the trade-wind system in the equatorial Pacific. The last such episode was in 1983; it was accompanied by a temporary northward shift in the range of a number of marine mammals and fish.

ASSESSMENT

One of the major concerns in the Pacific marine ecosystem is that some important stocks of salmon, especially chinook and chum, have declined significantly over the past few decades. The reasons for this appear to be several: over-harvesting and modification of spawning and feeding habitat by agriculture, forestry and hydro-electric development. A concerted effort has been made to enhance salmon production by releasing hatchery fish into salmon rivers. However, the adverse effects of these fish introductions on naturally generated stocks may, to some extent, offset gains from hatchery production.

Contamination from sewage has forced the closure of a number of shellfish areas near urban or industrial areas (particularly in the Strait of Georgia). Sewage may act as pollution plugs, impeding fish from moving up coastal rivers such as the Fraser to spawn; it may also be responsible for summer dieoff of fish in the lower Fraser. Blooms of *Gonyaulax* may have become more frequent in recent years, and the frequency and extent of outbreaks could be related to increased sewage contamination.

Organics and heavy metals are detectable in the major estuaries, particularly in the lower Fraser. Excessive levels of organics and heavy metals in fish have been noted in areas of the lower Fraser close to waste treatment plants and industrial sites.

Except for regions in close proximity to urban and industrial areas, however, B.C. coastal waters are relatively free of excessive levels of contaminants. Moreover, in offshore waters, contaminants are scarcely detectable.

NORTHERN MARINE ECOSYSTEM

INTRODUCTION

The arctic and subarctic seas of Canada cover a vast area, from the Beaufort Sea to Lancaster Sound, from north of Ellesmere Island to as far south as the Strait of Belle Isle. Thus far, there is little comprehensive monitoring of conditions in this vast region, but human activities continue to modify the ecosystem.

An ideal set of indicators of the state of the northern marine ecosystem would include measures of primary productivity (plant production, including phytoplankton); the status and change over time of major components of the biota (fish, marine mammals, waterfowl); nutrient conditions in arctic waters; and concentrations of contaminants in sediments, water and biota. Although more information on the arctic marine environment has become available in recent years, most of it is based on special studies rather than comprehensive databases.

This section begins with a description of the northern marine ecosystem, including the major water masses, the biological significance of ice, and the interaction between land and fresh and salt water. Then follows a discussion of conditions in the northern seas, reporting the available data on contaminant levels and the status of major marine mammal stocks. The third part describes the major influences on the state of the northern seas — climate, pollution, physical restructuring and harvesting. The final part provides a qualitative assessment of the arctic environment in relation to the various influences acting on it.

OCEANIC PROCESSES IN THE NORTHERN MARINE ECOSYSTEM

A full discussion of the northern marine environment ought to include a description of temperature regimes, water masses and currents, vertical water movements important to annual plant nutrient renewal, and the influence of ice on physical and biological subsystems. All these make up the physical environment of the ecosystem. The major biological processes include the concentration and renewal of plant nutrients (inorganic salts, such as phosphates, nitrates and silicates); the growth pattern and concentration of plants (phytoplankton, benthic diatoms, seaweeds); the grazing by herbivorous zooplankton; and the action of carnivorous plankton, fish, birds and sea mammals.

There is also considerable interplay between the land and fresh water on the one hand, and the marine ecosystem on the other. For instance, rivers transport soils that contribute to the nutrient input and food supply of inshore marine areas (e.g., the Mackenzie River plume); river outflow contributes to upwelling of plant nutrients; and glacier breakup has hydrodynamic effects on inshore waters. There are also food chain links, such as the consumption of marine animals by cliff-dwelling and land-breeding birds, and the predation of young seals by coastal arctic foxes. Some, but not all these topics are dealt with in this section.

Water Masses, Circulation, and Transport

For purposes of analyzing water circulation, the deep water of the Central Arctic Basin can be ignored. The oceanographic systems of interest are the Arctic water, comprising the upper 200 metres of the Arctic Ocean, the Atlantic water, and the Pacific water. Freshwater outflow is very small compared with these three giants, but it is nevertheless locally important, particularly in enclosed basins such as Hudson Bay and the southern Beaufort Sea.

Ice and its Biological Significance

Quite apart from the obvious value of sea ice as a platform for seals and walrus, ice has certain important biological effects. The presence of ice greatly reduces the penetration of light into the sea water below, thus affecting its photosynthetic potential. The surface layer of sea water becomes diluted by the leaching out of salt during the freezing process in the winter. This has the effect of producing a stable upper layer of water, some 50 to 75 metres thick, that effectively inhibits upwelling or vertical exchange of water, thus keeping the supply of nutrients (phosphates, nitrates, silicates) low.

The presence of ice also provides the northern seas with some unique characteristics, including ice biota, ice-edge effects, polynyas and glacial ice.

Ice Biota

An intense growth of plant cells, mainly diatoms, in the lowest layer of sea ice, and often at other levels in the ice as well, forms the basis for a specialized ecosystem. The diatoms appear in late winter but can also be present earlier in the season, depending on latitude and light conditions. The species making up these flora are adapted to low light intensity, and most of them are found normally in the bottom sediment. Records from the Beaufort Sea indicate that the ice biota represent between 10 and 30 per cent of the total Arctic Ocean phytoplankton population.[1] The ice diatoms support a complex but specialized fauna, from worms and crustacea to fish, birds and mammals.

Ice-edge Effects

The association of sea ice edges with an abundance of fauna is longstanding. For centuries navigators have recorded that there was a noticeable concentration of whales, seals, birds and "lower life" in these areas. But it was not until recently that the key role of upwelling at the ice edges was identified as the basis for the life support system.[5] By providing a renewable source of nutrients from deeper waters,

upwelling fuels the food chain. Under conditions that are not by any means fully understood, local upwellings are engendered at the faces of tidewater glaciers (glaciers coming down into fairly deep water).[24] Similar phenomena have also been discovered at the edge of large icebergs.[35]

Polynyas

Only recently has there been a definitive study[43] of ice-free or nearly-ice-free areas in winter sea ice — referred to as polynyas — and their ecological importance is only beginning to be realized. They provide seasonal refuges and feeding areas for walrus, certain seals, and polar bears. Whales are not dependent upon them because they migrate out of ice-covered regions in winter. The critical importance of polynyas lies in their potential for upwelling as a result of locally generated convection currents. In the larger polynyas, upwelling also occurs as warmer water reaches the surface.

The presence of large polynyas may explain the surprising biological fertility of certain regions, notably Lancaster Sound and the Beaufort Sea. It has been impossible so far to find the source of the nutrients that must be responsible for this high production. What appears to happen is that polynyas function as enormous nutrient pumps, drawing micronutrients from a large area well beyond the limits of the ice-free area. The locations of arctic polynyas are shown in Figure 5.34.

Glacier Ice

Under conditions not fully understood, local upwellings are engendered at the faces of tidewater glaciers. These were first studied by Hartley and Dunbar in the Disko Bay region of western Greenland.[24] Neshyba found upwelling caused by large icebergs in the Antarctic,[35] and Foldvik and Kvinge described thermohaline convection at the edge of the Antarctic Ice Shelf.[18] Greisman has published a theoretical treatment of these phenomena.[23] They are ecologically important where they occur and form local feeding areas for certain sea birds and seals.

Land, Fresh Water and the Marine Environment

Probably the single most important ecological factor linking land and sea is freshwater inflow and its effects. The estuarine entrainment effect* is an important mechanism by which plant nutrients are lifted from deeper water to the photic zone.

The sediment contribution of large rivers to the sea is sometimes significant, as in the case of the Mackenzie River, which forms the Mackenzie plume, carried northeastward from the mouth of the river for some hundreds of kilometres. The sediments form a rich substrate upon which benthic flora and fauna live.

CONDITIONS IN THE NORTHERN MARINE ECOSYSTEM

Contaminants from Human Activity and Natural Sources

Some of the best data on contaminants from human activities were obtained from two summer survey cruises in the Beaufort Sea (1974 and 1975). Their purpose was to provide baseline data for the anticipated rise in contaminants from petroleum exploration and extraction. Their findings were that practically no contaminants of human origin were found in the area surveyed. Hydrocarbon concentrations were low or close to detectable limits, indicating an absence of petrogenic inputs. Methane levels in the near bottom waters were comparable to levels from natural sources (i.e., seepage or natural influx from sediments).[46]

Another study examined the coastline of the Beaufort Sea and found no extensive tar pollution and no natural seepage. Plastic wastes, in particular explosive cannister fragments from seismic activity, were found along the shoreline.[47]

The relatively high concentration of hydrocarbons in the waters of some of the eastern arctic regions (e.g., Scott Inlet, the entrance to Lancaster Sound) suggests that natural seepage of petroleum from the seabed is a major source of petroleum residues in some areas.*[28]

Trends in Major Marine Mammal Populations

The Bowhead Whale (*Balaena mysticetus*)

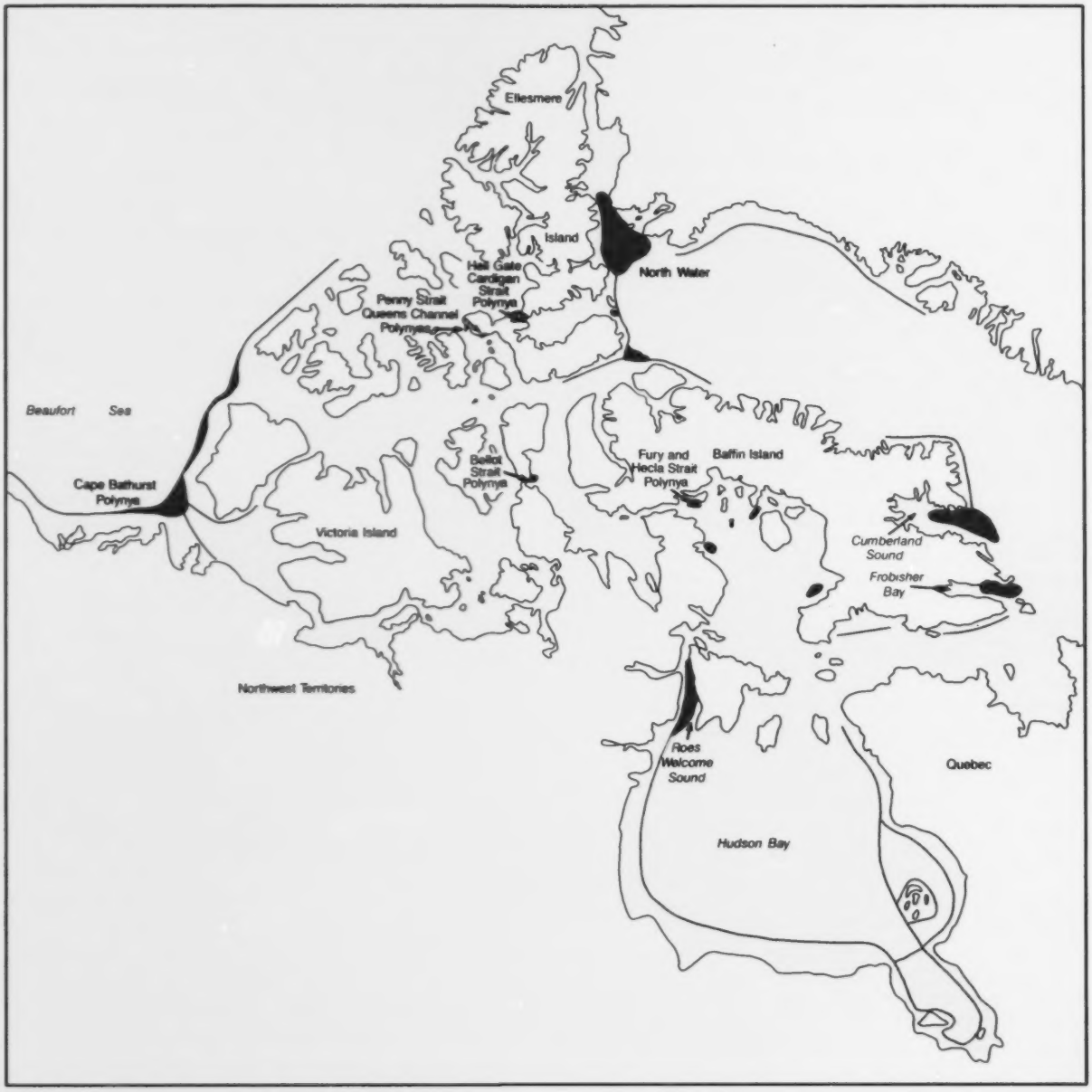
Canadian stocks of this circumpolar species are found in the eastern Arctic Ocean and the Bering Sea; the latter stock migrates into the Beaufort Sea in summer. Two recent studies describe the history and present status of these two stocks.[31,37]

The Bering Sea stock, estimated at about 18 000 animals in the mid-nineteenth century, has been reduced to between 600 and 2 000 by hunting. The original size of the eastern Arctic stock is uncertain, but it probably exceeded 11 000 in 1825. Whaling operations in the eastern Arctic began in 1719. The bowhead was considered almost extinct in the Baffin and Hudson Bay regions in the early years of this century, and it has subsequently been completely protected from commercial exploitation. The present stock (the size of which is difficult to estimate) is thought to be only a few hundred individuals.[33]

*The entrainment effect refers to a backflow of salt water in river estuaries. The outflow of fresh water creates a reverse shoreward current that carries deep water laden with nutrients to the head of the estuary.

*It has been estimated that about 0.6 million tonnes of petroleum per year enter marine waters from the continental shelf areas of the world — about one-tenth of man's contribution.[32]

Figure 5.34
Distribution of Recurring Polynyas in the Canadian Arctic



Shore lead systems contain variable-sized areas of semi-permanent open water during the winter and are the first and most persistent areas of open water in the spring. Because they are linear, shore leads technically do not qualify as polynyas but are included for their biological significance.
Source: I. Stirling and H. Cleator, eds., *Polynyas in the Canadian Arctic*, Occasional Paper No. 45 (Ottawa: Canadian Wildlife Service, 1981).

Table 5.21
White Whale Catch in the Western Arctic, Eastern Arctic, Hudson Bay and James Bay, 1951-1973

	Zone			
	Western Arctic[1]	Eastern Arctic	Hudson Bay and James Bay	Total
1951	0	292	591	883
1952	0	204	788	992
1953	0	285	681	966
1954	210	201	616	1 027
1955	0	232	557	789
1956	0	138	476	614
1957	0	199	844	1 043
1958	0	279	550	829
1959	54	487	302	843
1960	145	308	510	963
1961	145		103	248[2]
1962	96	172	392	660
1963	94	133	560	787
1964	30	109	727	866
1965	30	38	701	769
1966	50	69	814	933
1967	40	214	507	761
1968	14	56	652	722
1969		27	328	355[2]
1970		85	326	411[2]
1971			13	13[2]
1972	120	61		181[2]
1973	297	63	178	538

[1]There was little fishing in the western Arctic during the 1950s.

[2]Data incomplete.

Source: D.E. Sergeant and P.F. Brodie, "Identity, Abundance and Present Status of populations of White Whales, *Delphinapterus leucas*, in North America", *Journal of the Fisheries Research Board of Canada* 32/7 (1975): 1047-1054.

The Narwhal (*Monodon monoceros*)

This species is a close relative of the white whale. Its most conspicuous feature is its long tapering tusk, which can protrude some 200 centimetres. The tusk is characteristic of the male, but is also found occasionally in the female.

Canadian narwhals are widely distributed in eastern Arctic waters to northwestern Greenland. They are found primarily along the east coast of Ellesmere Island, in Jones and Lancaster Sounds, in Prince Regent Inlet, Navy Board Inlet, Pond Inlet, at Clyde River on the east coast of Baffin Island and at Repulse Bay in northern Hudson Bay.

A conservative estimate of the total narwhal population of Canada and northwestern Greenland is 10 000.[30] They are thought to have been over-hunted, but there are no reliable data on total catch. RCMP game reports and other available sources are known to be incomplete.

The Beluga Whale (*Delphinapterus leucas*)

A recent stock assessment of the belugas (white whales) of northern Quebec suggests that three stocks are of primary importance.[17] A transient stock of about 8 000 to 9 000 animals winters in Hudson Strait and Ungava Bay, migrating to summering areas in western Hudson Bay. A summer-resident stock in Ungava Bay, severely reduced from historical levels, consists of fewer than 100 individuals. The third stock summers along the east coast of Hudson Bay and consists of a few hundred animals, down from historical levels of perhaps 5 000 individuals.

Catch statistics for this species for the western Arctic, eastern Arctic, Hudson Bay and James Bay are given in Table 5.21. The data cover the period 1951-1973 and show large fluctuations in the western Arctic and declines for the other areas.[40]

Hunting of beluga decreased over the period 1965-1975, from average kills of 1 000 to 500. These are believed to be well below the sustainable yield, which is unknown. Only in Cumberland Sound have the local populations been depleted well below sustainable levels.

Trends in Major Arctic Fisheries

There are no truly northern marine commercial fisheries. The subarctic fisheries of Labrador have been aggregated with those of the Atlantic marine ecosystem, dealt with earlier in this chapter.

The main arctic fishery is for char, an anadromous species fished almost entirely in arctic freshwater systems. Char has long served as an important Inuit fishery, but recently it has become commercial. Records of total catch and catch per unit effort for several arctic locations suggest that some important stocks are stable and supporting a viable commercial fishery, while others have become seriously depleted from over-fishing.

INFLUENCES ON THE NORTHERN MARINE ECOSYSTEM

The state of the northern marine ecosystem is determined by a number of influences, both natural and human. This section describes some of the major stresses and documents their magnitude as far as possible.

Climate Change

Climate and sea temperature changes influence the northern marine environment. For example, there was a remarkable rise in sea-surface temperatures in western Greenland waters between 1920 and 1935, a second peak about 1960 and a decline in 1970.[12] The 1920s saw the development of a large cod fishery in western Greenland, the direct result of these changes. Atlantic cod began to appear in those waters about 1917, coming from Iceland and returning there in the fall. Later they established breeding populations in Greenland coastal fjords and reached as far north as Upernavik at latitude 72°.[25] A warmer period recorded in the 1880s had less pronounced effects, but it was enough to bring the cod there for a few years. At the same time seals and whales responded to warmer temperatures by moving into northern Greenland waters as the cod invaded the southwest.

On a somewhat longer time scale, it has been postulated that shifts in the range of Atlantic salmon are related to climatic change.[14] The locations of the sea-life of salmon were unknown until recently. The fish have now been found in great abundance in the Davis Strait area west of Greenland. This area has been fished and whaled for four centuries; had salmon been present earlier in large numbers, their presence would have been noted. Although the mechanism responsible for changes in salmon distribution has not been established, there is evidence that salmon have appeared on the western Greenland coast during periods of cooling following temporary upswings in sea-surface temperatures. Climatic change may also be responsible for changes in the abundance of seals and polar bears in the Beaufort Sea.[41,42,44]

Pollution from Human Activities

Contaminants from Diffuse Sources

Increasingly, pollutants are entering arctic waters by circulating from adjacent seawater. Evidence of the wide circulation of contaminants was discovered some years ago when DDT was found in antarctic fauna. Chlorofluoromethanes, in particular, have recently been measured in the Greenland and Norwegian seas.[6] Heavy metals, herbicides, and pesticides are also finding their way into the marine circulation, some of which enters Canadian arctic and subarctic waters from elsewhere. Contamination from diffuse sources has not led to significant concentrations of pollutants in arctic waters according to two summer surveys of the Beaufort Sea in 1974 and 1975.

Contaminants from Point Sources

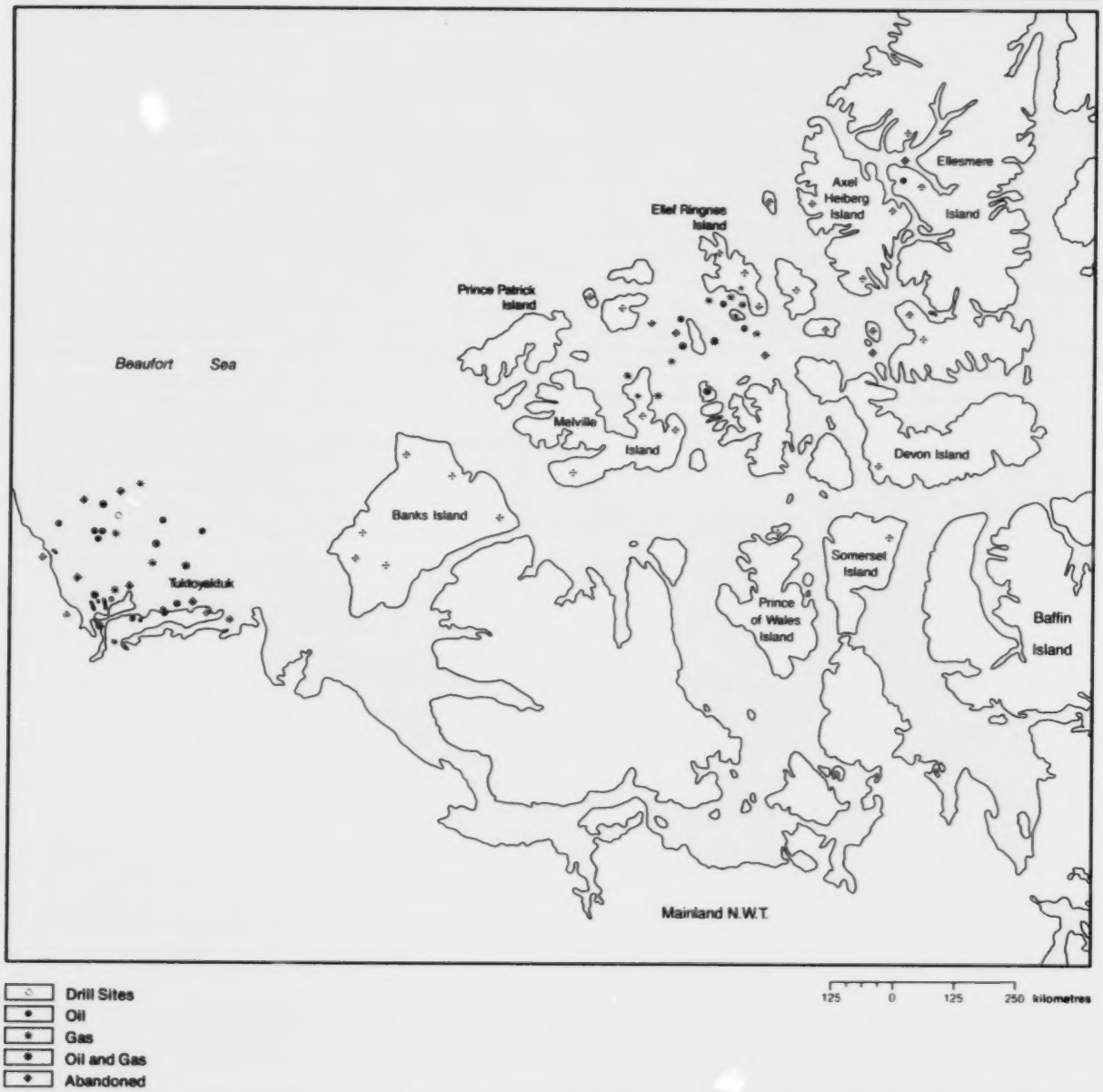
Hydrocarbon Exploration and Development. This subject has received much attention over the past 10 to 15 years. The alarm raised by environmentalists a decade ago[36] seems to have subsided somewhat, but the environmental danger has not disappeared. Threats come from direct pollution by oil, environmental disturbance of drilling sites, and shipping. Recorded spills or blow-outs in the north and resulting changes to the environment have seldom been documented. Experimental oil spills on a small scale, carried out during the Beaufort Sea project by Dome Petroleum (1980) and in Eclipse Sound, Baffin Island, by others, have shown that the fate and behaviour of spilled oil depend very much on ice conditions.

The general conclusions reached are tentative, and the effects of oil spills in arctic waters seem unpredictable given the present state of knowledge.[34,8,29]

Offshore Drilling in Circumpolar Areas. The circumpolar array of drill sites may, through ocean circulation, disperse hydrocarbons in these remote waters, in a manner similar to the atmospheric circulation of industrial waste residuals. Direct drilling operations, such as those currently taking place in the Beaufort Sea or planned off the west coast of Greenland, may disperse oil residues through ocean currents (e.g., the Labrador current) along the Baffin Island and Labrador coasts. Such dispersion could pose a threat to the arctic ecosystem.

Mining. A study of contaminants from mine tailings from the Nanisivik mine on Baffin Island was conducted between 1974 and 1979.[16] The objective was to compare pre-mining conditions with those after the mine went into operation in 1976. This monitoring program revealed that substantial increases in concentrations of lead, zinc and arsenic in sediments, seaweeds, sea urchins and molluscs took place in the vicinity of the marine terminal of the mining operation in the three years following the start of production. Lead and zinc concentrations in sea urchins and zinc concentrations in molluscs exceeded recommended levels for marine animal products established by the Department of National Health and Welfare.[16]

Figure 5.35
Oil and Gas Exploration Sites in the Beaufort Sea and Arctic Islands



Drill sites shown on this map are generalized. For more detailed information, contact the Canada Oil and Gas Lands Administration.
Source: Department of Energy, Mines and Resources, Canada Oil and Gas Lands Administration, 1985.

Physical Restructuring

Oil and gas exploration and development involve structures that may have local environmental effects. These include artificial drilling islands and shore facilities, including piers and causeways between islands and out from the shore. The locations of artificial islands and other well sites in the Beaufort Sea are shown in Figure 5.35.

These structures seem not to have had adverse effects on the local marine environment as yet. For example, the causeway built in Prudhoe Bay does not seem to have had any ecological effects apart from a shift in the sedimentation pattern. Migrant fish have not been disturbed, and a recent workshop on the planned extension of the causeway concluded that the extension would do no harm.

The conference on arctic energy resources organized by the Comité Arctique (1982) brought together much expertise on offshore oil and gas development. The Beaufort Sea received special attention. Again, no environmental damage from exploration was reported, but the difference in scale between exploration and development was made very clear.

Floating ice platforms for oil and gas exploration have been in use since 1974 in the waters off the Arctic Islands.[15] To date 22 platforms have been built and 13 exploration sites have been drilled, and no deleterious environmental effects have been reported.

Icebreaking as a result of shipping has caused concern on several grounds: (a) the disruption of Inuit (and animal) winter routes over ice, especially across channels; (b) the possibility of diverting whales and other marine mammals into ship-made leads which, when they freeze, might trap the animals and drown them; (c) the disruption of ice edges with consequent biological response; (d) the effects of noise on marine mammals; and (e) possible flooding of ice habitat (e.g., birth lairs).

The Ikajutit Hunters and Trappers Association (Arctic Bay) urged that shipping through Admiralty Inlet to Strathcona Sound be banned until August each year, because it disrupts the activities of Native hunters and their families. Icebreaking, they claim, makes it difficult or impossible to predict how the ice will move. It also restricts movement on the ice and does not allow access to all hunting areas. The Association also had evidence that narwhals were being forced by shipping traffic through Admiralty Inlet to retreat down Prince Regent Inlet and reach the northern part of Foxe Basin through the Fury and Hecla Strait, where they had become trapped and drowned.

It is less likely that a change in ice edges would have significant effects. Ice edges reform rapidly, and in any case their extension could be expected to be biologically beneficial, rather than the reverse.[10]

Harvesting

This section considers evidence concerning the over-harvesting of selected marine mammals and fish. The bowhead, narwhal and beluga whales were discussed earlier. Here we focus on the harvesting pressure on these stocks, examining such data as are available on local catch and reproductive potential.

As noted earlier, the bowhead is protected from harvesting. It should be pointed out, however, that both beluga and narwhals are in danger of being over-cropped. A stock of 10 000 narwhal should produce something close to 900 young. If, as in 1957, the kill, including animals shot and lost, is 1 154, the take is likely in excess of the sustainable yield (i.e., replacement of the stock by reproduction, less natural mortality).

The beluga of the east coast of Hudson Bay have a history of commercial exploitation characterized by over-exploitation and collapse of the stock and fishery, followed by a recovery period. For example, a fishery was established in 1853, with 3 500 whales being taken in 7 years before the fishery collapsed. Another cycle occurred in the late nineteenth century. Today, the stock is harvested for subsistence use. It is severely reduced from historical levels of (possibly) 5 000 animals, and the current annual harvest of 100 to 200 animals will probably cause complete collapse of the fishery in a few years.

The stock of beluga whales that summers in Cumberland Sound on Baffin Island was first exploited commercially in 1920. During the 1920s, as many as 800 animals were taken annually. A stable catch of about 150 animals was taken from 1948 to 1960. Catches then declined to approximately 45 to 50 animals until 1976 when they climbed to more than 100. Aerial counts made in 1967 and 1977 estimated the population at approximately 700 animals. In 1980 the population was estimated at 450 animals, probably reflecting the increased kill in the late 1970s. In 1980 a quota of 40 animals, based on estimates of annual production from the reduced population, was instituted. Research and aerial counts continue to refine this estimate, while enforcement and consultation with local hunters are being pursued in an effort to prevent collapse of the stock and the subsistence fishery.

With respect to fish, the arctic char (*Salvelinus alpinus*) has been depleted in some areas. There are some well documented examples of stocks being seriously depleted by over-harvesting. Char are slow to recover; females do not begin to breed until they are 12 years old and often do not breed every year.[22]

The arctic char of Sylvia Grinnell River on Baffin Island were historically exploited by the Inuit for food. A commercial fishery was conducted during the period 1947-1950, followed by a period of subsistence and sport exploitation until 1957. In 1958 a commercial fishery was established; it harvested a quota of

Table 5.22
Harvest and Mean Size of Arctic Char of Sylvia Grinnell River on Baffin Island, 1948-1977
(kilograms)

	Total Harvest	Mean Size
1948-1950 (Mean)	14 550[1]	2.95
1958	17 834[1]	2.20
1959-1966 (Mean)	17 401[1]	NA
1977	3 669[2]	0.48

[1]Commercial, angling, subsistence and snagging.
[2]No commercial.
Source: A.H. Kristofferson and R.D. Sopock, "The effects of exploitation in the Arctic Char population of the Sylvia Grinnell River, Northwest Territories", *Canadian Management Report of Fisheries and Aquatic Sciences* (1983).

4 500 kg annually until 1963, when return for effort and fish size both began to decline; the commercial fishery was closed in 1966. Today the stock still supports a small recreational and subsistence fishery, but the poor yield and small fish indicate that the stock has never recovered from over-harvesting (Table 5.22).

The commercial char fishery at Cambridge Bay in the central Arctic has been more successful. Ekalluk River was fished at first, with a quota of 18 000 kg. In 1967 a single quota was established for all of Wellington Bay, into which the Ekalluk flows, based on the estimated stock of char in all the rivers entering the bay. During the next two years, fishing remained concentrated in the Ekalluk River. In 1959 the Ekalluk River fishery collapsed and was closed for three years. Regulations then imposed called for a large mesh size; enough mature fish were left to allow the stock to recover, and the fishery was reopened. The rivers in the area are now assigned individual quotas based on careful assessment, including enumeration of fall runs and tagging for stock identification. Today the stocks appear to be stable and support the largest arctic char fishery in the Territories, with annual landings of over 50 tonnes.

ASSESSMENT

Given the scarcity of data on change in critical parameters, an overall assessment of conditions in the northern marine ecosystem must of necessity be qualitative.

There is little doubt that major changes have occurred in the dominant biota. Some or all of the commercial species of whales have been over-harvested, and estimated stocks today are well below historical levels. This applies to the bowhead, narwhal and beluga. Harvesting may not have been the only influence on declines in these species, but it appears to be the dominant influence. No doubt other factors that normally produce ups and downs in marine populations also affect these stocks, but the role of such influences as climate change on marine mammals in the arctic system is unclear.

Major concern about the northern marine ecosystem remains centred on the threat from accidental or continuous spills of contaminants, particularly oil and gas residues in connection with exploration and extraction. Considerable uncertainty surrounds these questions. There have been no major spills in arctic waters and thus no hard data on which to base predictions. What is known, however, from extrapolating results elsewhere and from local experiments in arctic waters, is that the effects depend very much on local ice conditions, currents, climate and seasonal factors.

Surveys of contaminants in the Beaufort Sea, carried out in the 1970s, suggest that these waters are relatively clean. In other parts of the Arctic where contaminants have been detected, these have been attributed to natural seeps (oil) or to local effects of dumping mining tailings.

Concern about physical damage from the construction of artificial islands, platforms and other structures used in exploration and extraction of undersea oil and gas deposits appears to have subsided after extensive impact assessment studies of structures already in place revealed little in the way of disruption of the arctic marine systems in which the structures are embedded.

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INTRODUCTION

With a land area of nearly 10 million square kilometres (6.9 per cent of the world's total), Canada provides an unusual diversity of natural habitat: grasslands, parklands, deciduous forest, coniferous forest, arctic tundra, and mountain habitat. It contains the world's greatest supply of fresh water; the country is dotted with lakes, from the world's largest to small potholes and ponds. The coastlines are complex, with cliffs, fiords, estuaries, and large fishing banks offshore.

The types of vegetation occurring in Canada can be grouped into three broad categories, tundra, forest and prairie, which are found in broad zones from north to south. In the mountains, alpine conditions allow typically northern fauna and flora to extend considerably southward — for example, rock and white-tailed ptarmigans (*Lagopus mutus* and *L. leucurus*) and bighorn sheep (*Ovis canadensis*) range quite far south along the Rocky Mountain chain.

The diversity of habitat gives rise to a rich variety of wildlife. Canada has 172 species of land mammals (Table 6.1), 5 per cent of the world's total, including 10 orders, 33 families and 102 genera. Canada is notable for large ungulates (bison, wood buffalo, moose, elk, muskox, bighorn sheep, mountain goat, deer and pronghorn antelope); their predators (cougar, timber wolf); bears (grizzly, black and polar); and marine whales, walrus and seals. Beaver, otter, bobcat, lynx, mink, marten and muskrat long supported a trading empire and were instrumental in the early economic development of Canada.

Canadian avifauna (Table 6.2) include representatives of 17 orders, 54 families, and 216 genera comprising some 380 species. Water birds include loons, grebes, pelicans, herons, geese, ducks and rails. The Canadian Arctic is pre-eminent in breeding shore birds, with 7 species of plover and 26 scolopacids. Ten auks and 19 gulls dominate the coastlines. There are 17 diurnal birds of prey (eagles, hawks, osprey) and 13 owls. Two species of dove, two of cuckoo, four of swift, three of hummingbird, and one of kingfisher, as well as 11 species of woodpecker and 179 species of passerine (flycatchers, warblers, thrushes, blackbirds, sparrows), are native to various regions. With 36 species of swan, geese and duck and 10 species of grouse, Canada is also rich in game birds.

North-south migration is almost universal; probably 95 per cent of all birds that breed in Canada migrate southward.* Wintering areas range from southern Canada (snowy owl, snow bunting, many ducks) or the offshore regions of the coasts (ducks,

*A few species of sea birds (shearwaters, petrels) migrate in reverse, breeding in the oceanic islands of the southern Atlantic and Pacific Oceans and wintering off the east and west coasts of Canada from June to September.

Table 6.1
Species Distribution of Major Groups of Canadian Mammals
(by dominant habitat)

	Atlantic Maritime	Boreal[1]	Mixed-Wood Plain	Prairie	Cordillera[2]	Pacific Maritime	Arctic[3]	No Dominant Habitat	Total
Marsupials[4]			1						1
Insectivores[5]	1	3	4		1	5		3	17
Bats		3	1		3	2		4	13
Lagomorphs[6]				2	1			3	6
Rodents[7]		9	4	11	14	9	8	11	66
Whales	5					7	3	9	24
Carnivores[8]		5	1	2		2	2	12	24
Seals & Walrus						3	6	1	10
Ungulates[9]		3		2	2		2	2	11
Total[10]	6	23	11	17	21	28	21	45	172

[1]Boreal includes Boreal Plain, Taiga Plain, Taiga Shield, Boreal Shield, and Hudson Bay Plain ecozones.
[2]Cordillera includes Tundra Cordillera, Boreal Cordillera, and Montane Cordillera ecozones.
[3]Arctic includes Southern Arctic, Northern Arctic, and Arctic Cordillera ecozones.
[4]Opossums.
[5]Shrews and moles.
[6]Rabbits.
[7]Mice, beaver, gophers, squirrels, porcupines.
[8]Dogs, cats, bears, raccoons, weasels.
[9]Mammals with hooves: sheep, deer, moose, antelope, caribou, muskox, bison, elk.
[10]These totals do not correspond exactly with those given in Banfield, 1977.
Source: Tabulation by A. Keast, Queen's University. Modified from source material compiled by Banfield (see reference #1).

Table 6.2
Species Distribution of Major Groups of Birds Breeding in Canada
(by dominant habitat)

	Atlantic Maritime	Boreal[1]	Mixed-Wood Plain	Prairie	Cordillera[2]	Pacific Maritime	Arctic[3]	No Dominant Habitat	Total
Loons							3	1	4
Grebes			1	2				2	5
Petrels	1					1		1	3
Pelicans/Cormorants	2					1		1	4
Herons		1	3					2	6
Ducks and Geese		11		1	6		9	9	36
Hawks		1	1	4			2	10	18
Grouse		3	1	2	2		2		10
Rails		2	2					2	6
Plover/Gulls	5	5	1	5	1	7	??	13	70
Pigeons						1		1	2
Cuckoos								2	2
Owls		3		1	1		2	6	13
Nightjars		1		1				1	3
Hummingbirds/Swifts					5			2	7
Kingfishers								1	1
Woodpeckers			1		3			7	11
Perching Birds		34	16	9	28	3	11	78	179
Total[4]	8	61	26	25	46	13	62	139	380

[1]Boreal includes Boreal Plain, Taiga Plain, Taiga Shield, Boreal Shield, and Hudson Bay Plain ecozones.
[2]Cordillera includes Tundra Cordillera, Boreal Cordillera, and Montane Cordillera ecozones.
[3]Arctic includes Southern Arctic, Northern Arctic, and Arctic Cordillera ecozones.
[4]More records are available from the Canadian Wildlife Service, Environment Canada.
Source: Compilation by A. Keast, based largely on W.E. Godfrey, *The Birds of Canada* (Ottawa: Queen's Printer, 1966).

auks), to the southern United States (most hawks, sparrows), to Central and South America (nightjars, flycatchers, warblers, a few ducks and hawks), and to the southern tip of South America and Antarctica (shorebirds and terns). Migration makes it difficult to assess causes of changes in bird population levels in Canada, for these fauna are presumably sensitive to changes in their winter habitats (e.g., deforestation in Central and South America) as well as to pesticide residues in food supplies along the migratory route. Nonetheless, the condition of the breeding habitat is of critical importance.

As with mammals, most bird species are restricted to, or are most abundant in, particular habitats. Table 6.2 shows that species distributions vary with different vegetation zones. Of the 380 species, only 139 — little more than one-third — are distributed across the Canadian mainland. This group includes water birds (whose distribution is not determined by terrestrial vegetation), some hawks, swallows, various woodpeckers, thrushes, warblers and finches.

Quantitative data on wildlife population change and distribution are difficult to obtain. In many cases, the limits of error reflect both inherent problems in counting individuals and the lack of the repeated intensive surveys required for more accurate counts.* For groups such as fur-bearers, changes in stocks can be inferred from records of harvest, taking into account that commercial harvests are as often determined by demand as by supply. For some of the larger mammals, particularly the marine mammals and arctic species, public concern has led to a steady im-

*The techniques for searching and sampling large areas are costly; the process is particularly difficult in the vast remote regions of northern Canada.

Table 6.3
Status of Major Big Game Species in Canada, 1984

Species	Species Sub-group	Population (000s)	Population Trend[1]	Distribution
Sheep	Dall	34.0	Stable	Tundra Cordillera, Boreal Cordillera
	Stone	12.3	Stable	Boreal Cordillera
	Rocky Mountain	8.7	Stable	Montane Cordillera
	California	4.5	Stable to increasing	Montane Cordillera
Deer	White-tail	660.0	Increasing	Montane Cordillera, Boreal Plain, Taiga Plain, Prairie, Boreal Shield, Mixed-Wood Plain, Atlantic Maritime
	Black-tail	310.0	Increasing	Boreal Cordillera, Pacific Maritime, Montane Cordillera
	Mule	230.0	Increasing	Montane Cordillera, Boreal Plain, Taiga Plain, Prairie
Moose		846.0	Stable to increasing	all but Prairie, Mixed-Wood Plain, Southern Arctic, Northern Arctic, Arctic Cordillera
Antelope		10.0-20.0	Stable	Prairie
Caribou	Grant's	150.0	Stable	Tundra Cordillera
	Barren-ground	1 239.3	Stable to increasing	Boreal Plain, Taiga Plain, Taiga Shield, Boreal Shield, Southern Arctic
	Woodland	740.1	Stable to increasing	Tundra Cordillera, Boreal Cordillera, Montane Cordillera, Boreal Plain, Taiga Plain, Taiga Shield, Boreal Shield, Hudson Bay Plain
	Peary	22.3	Decreasing	Northern Arctic, Arctic Cordillera
Muskox		45.0	Increasing	Southern Arctic, Northern Arctic, Arctic Cordillera
Bison	Wood	1.25	Increasing	Boreal Plain, Taiga Plain, Taiga Shield
	Plains	2.0	Increasing	
	Hybrid	5.0	Decreasing	Boreal Plain, Taiga Shield
Elk		61.0	Stable	Pacific Maritime, Montane Cordillera, Boreal Plain, Prairie

[1]Population trend over period of 10 years.
Source: N. Novakowski, Thurlow and Associates, Ottawa.
Environment Canada, Canadian Wildlife Service, Western and Northern Region, Edmonton (caribou and antelope figures).

provement in reporting, although the data quality is still, in most cases, far from satisfactory.

The next section of this chapter provides an overview of the status of big game and fur-bearing animals and waterfowl, and a summary of endangered species in Canada.

We go on to consider wildlife trends and conditions. Data on important wildlife stocks are often spotty, and estimates are of varying accuracy and reliability. Therefore trends in wildlife conditions usually have more qualitative than quantitative significance. In a few cases, population estimates are supplemented by information on range and changes in range (habitat) over time.

This is followed by a section describing some of the major influences on wildlife. Man-made changes in land use, hunting and trapping, pollution, urbanization, and the accidental or intentional introduction of exotics have been major forces moulding the composition of wildlife in most ecozones. Among the natural influences, climate change in particular alters distribution patterns of plants and animals over time.

Finally, the assessment section offers a preliminary and largely impressionistic perspective on trends and conditions in Canadian wildlife. A more rigorous analysis must await more reliable data and research relating wildlife changes to a variety of influences.

Table 6.4
Status of Major Fur-bearers in Canada, 1984

Species	Species Sub-group	Population[1] (000s)	Population[2] Trend	Distribution
Beaver	many sub-species generally undistinguishable	4 000	Increasing	all but Southern Arctic, Northern Arctic, Arctic Cordillera
Muskrat		27 000	Stable to increasing[3]	all but Southern Arctic, Northern Arctic, Arctic Cordillera
Squirrel	red squirrel dominant species	8 000	Increasing[4]	all but Mixed-Wood Plain, Southern Arctic, Northern Arctic, Arctic Cordillera
Cats	lynx	250	Stable (lynx)[5]	all but Pacific Maritime, Prairie, Mixed-Wood Plain, Southern Arctic, Northern Arctic, Arctic Cordillera
	bobcat	25	Increasing (bobcat)[6]	all but Pacific Maritime, Prairie, Mixed-Wood Plain, Southern Arctic, Northern Arctic, Arctic Cordillera
Other	river otter	100	Stable to increasing	all but Prairie, Southern Arctic, Northern Arctic, Arctic Cordillera
Wild mink		800	Stable to increasing[7]	all but Southern Arctic, Northern Arctic, Arctic Cordillera
Weasel	total includes ermine, long-tailed and least weasels	2 500	Increasing (ermine) Stable to decreasing (long-tailed weasel) Stable (least weasel)	
Fisher		50	Stable to increasing[8]	Boreal Cordillera, Pacific Maritime, Boreal Plain, Boreal Shield, Hudson Bay Plain, Atlantic Maritime
Martin		400	Stable[9]	all but Mixed-Wood Plain, Southern Arctic, Northern Arctic, Arctic Cordillera
Raccoon		600	Stable to increasing	Pacific Maritime, Montane Cordillera, Prairie, Boreal Shield, Mixed-Wood Plain, Atlantic Maritime
Black bear		150	Increasing	all but Prairie, Southern Arctic, Northern Arctic, Arctic Cordillera
Fox	coloured fox	350	Stable (coloured fox)	all but Northern Arctic
	white fox	750	Stable (white fox)[10]	Taiga Shield, Southern Arctic, Northern Arctic, Arctic Cordillera
Wolf		50	Stable	all but Prairie, Atlantic Maritime
Coyote		325	Increasing[11]	all but Taiga Shield, Hudson Bay Plain, Southern Arctic, Northern Arctic, Arctic Cordillera

[1]Total population derived as a function of potential harvest taken from *Report on the Status of Canadian Wildlife use by the Fur Industry*, Revised Edition (Ottawa: Department of Industry, Trade and Commerce, 1978). The factor used for potential harvest is 20 per cent of total population.
[2]Population trends for fur-bearers are based on assessments generally over the past 30 years.
[3]Some major muskrat areas not fully utilized, hence population estimate is *low*.
[4]Most jurisdictions report under-utilization because squirrel trapping increasingly is not cost-effective; hence population estimate is *low*.
[5]Cyclical species, but over 100 years of trapping does not seem to have altered total population except in the Atlantic Maritime ecozone.
[6]Limited distribution in Canada (southern latitudes).
[7]Under-utilized in most jurisdictions.
[8]Re-occupation of historical range in Ontario.
[9]Harvest controlled through quota system in most jurisdictions.
[10]Cyclical species, population numbers quoted probably near minimum.
[11]Natural expansion of range in maritime provinces and northern territories occurring.
Source: Personal Communication, N. Novakowski, Thurlow and Associates, Ottawa, 1984.

OVERVIEW

Tables 6.3 and 6.4 provide a qualitative assessment of population status and trends in major big game mammals and fur-bearers, most of which are of considerable economic importance, forming the major targets of commercial and sport trapping and hunting. Most of the populations seem to be stable or increasing, with the notable exception of the threatened Peary caribou and the hybrid bison.

An impressionistic summary of the population and status of waterfowl species is presented in Table 6.5.

A list of rare and endangered species has been produced by the Committee on the Status of Endangered Wildlife in Canada. The current Canada-wide listing of threatened, endangered, extirpated and extinct species of mammals, birds and fish is provided in Table 6.6 and summarized in Table 6.7. Although the number of threatened and endangered species is comparatively small, the importance to Canadians of (for example) the bowhead whale or the wood bison cannot readily be dismissed.

Table 6.5
Status of Major Groups of Waterfowl in Canada, 1984
(with trends in 1980-1984)

	Population (millions)	Trend 1980-84	Breeding distribution (ecozones used by majority)
Dabbling ducks (Anatini): 7 species	26.2	Decreasing	Boreal Plain, Prairie, Boreal Shield, Mixed-Wood Plain
Wood duck	0.3	Increasing	Mixed-Wood Plain
Ruddy duck	0.3	Stable	Boreal Plain, Prairie
Diving ducks (Aythyini): 5 species	9.9	Stable	Boreal Plain, Taiga Plain, Taiga Shield, Boreal Shield
Sea ducks (Mergini): 13 species	8.6	Stable	Pacific Maritime, Taiga Plain, Taiga Shield, Boreal Shield, Southern Arctic
Total ducks	45.3	Decreasing	
Canada goose	2.5	Stable	Boreal Plain, Taiga Plain, Taiga Shield, Boreal Shield, Hudson Bay Plain, Southern Arctic
Greater snow goose	0.2	Increasing	Northern Arctic
Lesser snow goose	1.8	Increasing	Northern Arctic, Southern Arctic, Hudson Bay Plain
Ross's goose	0.1	Increasing	Southern Arctic
White-fronted goose	0.2	Increasing	Southern Arctic
Pacific brant	0.1	Decreasing	Northern Arctic
Atlantic brant	0.1	Increasing	Southern Arctic, Northern Arctic
Total geese	5.0	Increasing	
Trumpeter swan	5.0	Increasing	Boreal Plain
Tundra swan	0.1	Increasing	Northern Arctic, Southern Arctic
Total waterfowl	50		

Source: Modified from North American Waterfowl Management Plan (draft, November 1985).

WILDLIFE CONDITIONS AND TRENDS IN DIFFERENT ECOZONES

Regional wildlife issues are as many and varied as the diversity of the landscape, economic activities, cultural patterns, and political climate. Major concerns generally involve threatened or endangered populations. In one region, the issue may be caribou, in another, a sub-species of bear or marmot. Where possible, we provide data on trends in, and conditions of, threatened populations, although in many cases the existing data are anecdotal. Even in some of the better documented cases, the quality of data is uneven, and most estimates of population are considered approximations.

The discussion includes some populations that are not in danger of extinction but are much reduced in some areas or are of special interest. Where species are of economic importance (as in the case of many waterfowl, fur-bearers, and big game species), the data are derived from breeding surveys (waterfowl) or harvest data. Issues involving threatened populations (polar bear and caribou) that range over several ecozones are treated at the end of this section.

Pacific Maritime

At least one million waterfowl, of 40 species, use the coastal face of the Fraser River Delta as a staging area during spring and fall migration, although the numbers present at any one time are much smaller. Shorebirds are even more numerous, with perhaps one million, of 24 species, remaining in mid-winter, as well as large numbers on passage. There are 6 species of gulls, with peak numbers of over 70 000 birds. Several hundred great blue herons use the delta for several weeks each winter.

In the past 50 years the delta face has been greatly changed. As the industrialization of the Fraser River Delta continues, and as more marinas, barge terminals, and deep-water loading terminals are built and airport and sewage treatment plants are expanded, the shallow-water areas and tidal mudflats used by the birds will disappear.

A remarkable feature of the Pacific Maritime region is the many sub-species of large mammals. For example, there are at least four sub-species of the black bear (*Ursus americana*) found only in this zone.*

*These are the Kermode bear (*Ursus americanus kermodei*), a white bear found on the coastal islands and the mainland opposite the Queen Charlottes, on Princess Royal Island and on the mainland near Terrace; the Queen Charlotte black bear (*Ursus americana carlottae*); the Vancouver Island black bear (*Ursus americana vancouveri*); and the lower mainland black bear (*Ursus americana altifrontalis*). In addition, there is an isolated population of grizzly, the Chelan grizzly (*Ursus arctos chelan*), far removed from the mountain grizzlies to the east.

Table 6.6
Vulnerable and Extinct[1] Species in Canada, 1985

	Threatened	Endangered	Extirpated	Extinct
Birds	Burrowing owl Ferruginous hawk Henslow's sparrow Peregrine falcon — tundrius White pelican	Eskimo curlew Greater prairie chicken Kirtland's warbler Peregrine falcon — anatum Piping plover Whooping crane		Laborandan Great auk Passenger pigeon
Mammals	Humpback whale (northern Pacific) Long-tailed weasel (prairie) Peary caribou Woodland caribou — maritime	Bowhead whale Eastern cougar Right whale St. Lawrence beluga Sea otter Vancouver Island marmot Wood bison	Black-footed ferret Swift fox[2]	Woodland caribou — Dawson
Fish	Shorthead sculpin	Acadian whitefish Gravel chub		Blue walleye Longjaw cisco
Reptiles and Amphibians		Leatherback turtle		
Plants	American Water-willow Blue ash Bluehearts Giant helleborine Kentucky coffee tree Mosquito fern Plymouth gentian Thrift Willow	Cucumber tree Furbish lousewort Heart-leaved plantain Pink coreopsis Pink milkwort Prickly pear cactus Small white lady slipper Small whorled pogonia Southern maidenhair fern Water pennywort		

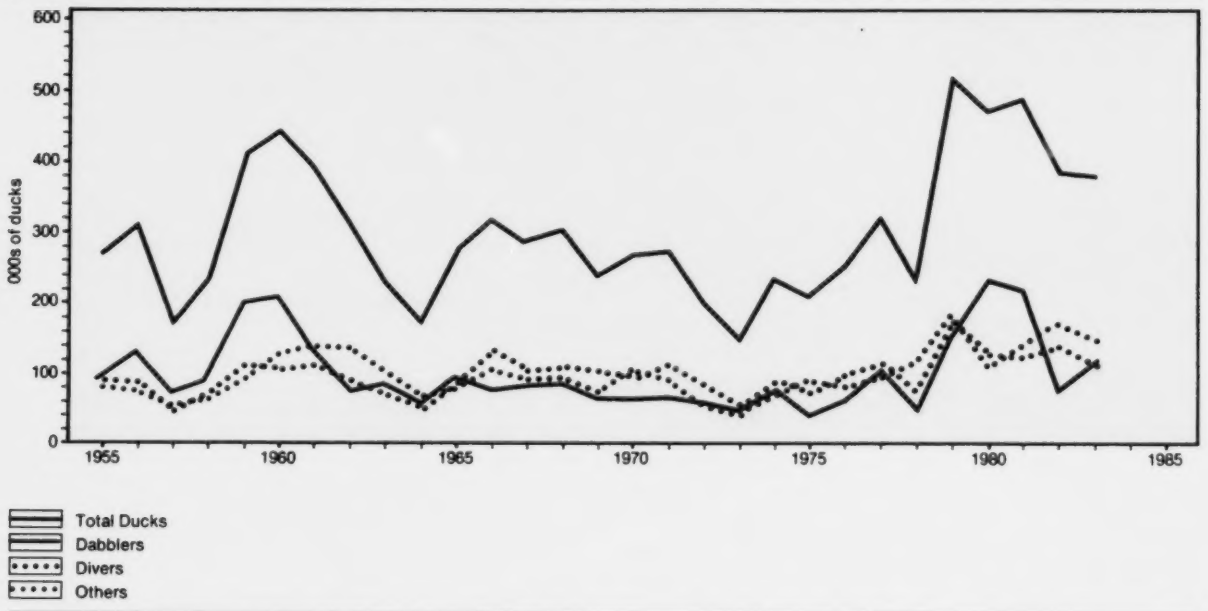
[1]National status as assigned in April 1985 by the Committee on the Status of Endangered Wildlife in Canada (COSEWIC). COSEWIC was founded in 1977 by the Federal-Provincial Wildlife Conference, to which it reports annually.
Threatened: Likely to become endangered in Canada if factors affecting its vulnerability are not reversed.
Endangered: Threatened with immediate extinction through all or a significant portion of its range, owing to the action of man.
Extirpated: No longer existing in the wild in Canada; existing elsewhere.
Extinct: No longer existing anywhere.
[2]This species has been re-introduced under a federal-provincial program on the prairies.
Source: Adapted from official list of the Committee on the Status of Endangered Wildlife in Canada, April 1985.

Table 6.7
Wildlife with Special Status
(as of April 1985)

Status[1]	Birds	Mammals (terrestrial)	Mammals (marine)	Fish	Plants	Reptiles and Amphibians	Total
Rare	14	7	2	15	6		44
Threatened	5	3	1	1	9		19
Endangered	6	4	3	2	10	1	26
Extirpated		2					2
Extinct	3	1		2			6
Not in any Category	7	7	1	1	1		17
Totals	35	24	7	21	26	1	114

[1]Definitions of Status:
Rare Species: Exists in low numbers or in very restricted areas in Canada but is not a threatened species.
Threatened Species: Likely to become endangered in Canada if the factors affecting its vulnerability are not reversed.
Endangered Species: Threatened with immediate extinction through all or a significant portion of its range, owing to the action of man.
Extirpated Species: No longer existing in the wild in Canada but existing elsewhere.
Extinct Species: Formerly indigenous to Canada but no longer existing anywhere.
Not in any category: Current status uncertain but evidently scarce.
Source: Committee on the Status of Endangered Wildlife in Canada, April 1985.

Figure 6.1
Ducks on the Old Crow Flats, Yukon, 1955-1983
(late May/early June)



Source: U.S. Fish and Wildlife Service, aerial survey, unpublished report, 1984.

None of these appears to be immediately threatened, although the Queen Charlotte black bear could become at risk in the future owing to habitat alterations from logging.

Populations of large animals in this zone seem to fluctuate widely. For example, the Vancouver Island wolf was thought to be threatened a decade ago[13] but is now numerous enough to be out of danger. The only endangered species in this ecozone, the Vancouver Island marmot (*Marmota vancouverensis*), is found in low numbers above the tree line on Douglas Mountain on western Vancouver Island.[10]

Cordillera (Montane, Tundra, Boreal)

This region contains several threatened and endangered species, as well as a wide variety of highly prized trophy species.

In the Montane Cordillera, the California bighorn sheep is found in groups spread across several areas in the Similkameen and Vaseux Lake areas, in the interior plains, and in the Chilcotin River-Riske Creek area. This threatened species now appears to be on the rebound, having increased from a population of 1 200 in 1961 to an estimated 6 000 to 8 000 in 1980.[18]

The Tundra Cordillera is an important breeding ground for Canada's most spectacular falcon, the peregrine (*Falco peregrinus*), which breeds on escarpments in the British Mountains (in the Yukon) and on cliffs along the Babbage, Blow, Firth, Old Crow and Porcupine Rivers. At least 16 eyries of the now endangered species had been identified by 1970. Surveys in the late 1970s revealed that here, as elsewhere in Canada, reproduction of the peregrine falcon had declined. These declines were linked to the accumulation of DDT taken up in food sources in the southern parts of the falcon's migration range from Canada to South America. DDT accumulation leads to eggshell thinning and poor hatching success. By the early 1980s, *Falco p. anatum* were still declining.[7] The introduction of *anatum* from captive rearing programs may serve to reverse the downward trend.

Waterfowl production in the Tundra Cordillera centres on the Old Crow Flats, a 13 000-square kilometre area of lakes, marshes and streams in northwestern Yukon, with a duck breeding population of about 300 000, peaking at 400 000 in 1960 and 520 000 in 1979 and with below-average numbers in the 1967-1976 period (Figure 6.1).

The Boreal Cordillera, particularly that of southern Yukon, is the major range for Stone's sheep (*Ovis dalli stonei*) as well as a habitat for mountain caribou (*Rangifer tarandus caribou*), moose (*Alces alces andersoni*), and grizzly (*Ursus arctos horribilus*). Populations of these trophy species have been relatively stable in recent years. Some concern has been expressed about a proposed Mackenzie valley pipeline, which would bisect the caribou range and thereby interfere with their migration patterns.

Table 6.8
Large and Small Mammals Once Common and Now Rare or Extirpated in the Prairie and Parkland Belt[1]

Large Mammals	Status	Small Mammals	Status
Plains bison	Extirpated	Red fox	Rare
Mountain sheep	Extirpated	Grey fox	Rare[2]
Grizzly	Extirpated	Mink	Rare
Wolf (*Canis lupus nubilis*)	Extirpated	Badger	Rare
Swift fox	Extirpated	Raccoon	Rare
Black-footed ferret	Extirpated	Bobcat	Rare
River otter	Extirpated	Lynx	Rare
Wolverine	Extirpated	Striped skunk	Rare
		Prairie dog	Rare[3]
		Kangaroo rat	Rare[4]
Elk	Rare	Bushy-tailed woodrat	Rare[4]
Wolf (*Canis lupus irremotus*)	Rare	Porcupine	Rare
Black bear	Rare	Beaver	Rare
Cougar	Rare	Franklin ground squirrel	Rare

[1]The Parkland Belt refers to the northern fringe of the Prairie ecozone which is vegetatively dominated by aspen.
[2]Southern Manitoba only.
[3]Saskatchewan prairies only.
[4]Alberta prairies only.
Source: Personal Communication, N. Novakowski, Thurlow and Associates, Ottawa, 1984.

Table 6.9
Population Estimates[1] of Major Fur-Bearers in the Boreal Plain Ecozone

Species	Ecozone total (000s)
Lynx	35
Beaver	488
Muskrat	4 500
Red squirrel	1 550
Coloured fox	48
Ermine	270
Mink	98
Skunk	355

[1]Population estimated conservatively at three times the sustainable long-term harvest. For purposes of calculation it was assumed that 75 per cent of Alberta provincial totals, 50 per cent of Saskatchewan provincial totals and 25 per cent of Manitoba provincial totals derive from the Boreal Plain ecozone.
Source: Based on Canada, Department of Industry, Trade and Commerce, *Report on the Status of Canadian Wildlife used by the Fur Industry*, Revised Edition (Ottawa: Minister of Supply and Services, 1978).

Prairie

The large animals of the great plains have been devastated by mass slaughter and transformation of their habitat. Over the past century, the natural prairie has all but disappeared. By 1900, significant portions of the southern Saskatchewan and Alberta grasslands were used for large-scale cattle ranching. Conversion of wildlife habitat to cattle range has led to reduced populations of wildlife. Many species once common in this region are now rare or extirpated (Table 6.8). Efforts to restore some of them are under way, but the area can never regain its original fauna. There is, for example, obviously little chance of re-introducing the great plains grizzly in the middle of cattle country.

The prairies are also one of the largest duck producing areas of North America. Figure 6.2 records the total number of ducks and mallards breeding in the Canadian prairies over the past 30 years. Both the number of mallards and the total number of ducks show considerable year-to-year fluctuations, reflecting, in part, changes in the availability of ponds (Figure 6.3). Part of the continuing population decline from the late 1970s onward is accounted for by the unusually prolonged drought in parts of this ecozone. A more serious cause has been the continued conversion of wetlands for agricultural use, involving not only the drainage of ponds but also the elimination of most of the adjacent nesting areas. As a result, duck nesting success on land is now so low that prairie populations cannot survive without immigration. Diving ducks, which nest on water, have fared better. Although much of the decline in prairie duck numbers is attributed to unfavourable breeding conditions, it is probable that the mallard, the most abundant and popular game duck, has also been over-hunted in recent years, especially in the southern United States, although this view is vigorously contested by some hunting organizations.

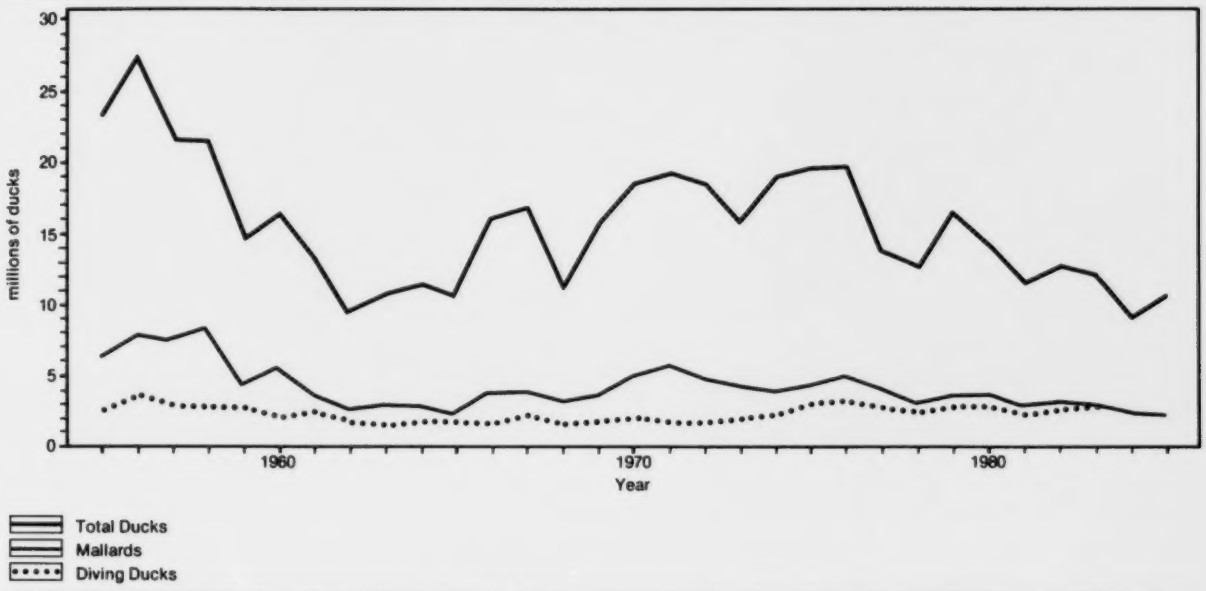
The Conifer Belt

Boreal Plain

This region is best known for its high productivity of fur-bearers, which support a significant trapping industry (Table 6.9). The great diversity and productivity of fur-bearers allow trappers to cope with fluctuations in abundance of particular species and/or market conditions.

The Boreal Plain is also significant for duck production. Figure 6.4 shows trends in the breeding population of northern Alberta, which makes up the greatest part of this ecozone, for the period 1955-1983. There were very large numbers in 1958 (nearly 7 million), 1959 (nearly 10 million), and 1961 (7.6 million), while in other years numbers varied between 2 million and 5 million without sustained trends. Figure 6.4 also includes the number of ducks using the Peace-

Figure 6.2
Ducks on the Canadian Prairies, 1955-1985
(millions)

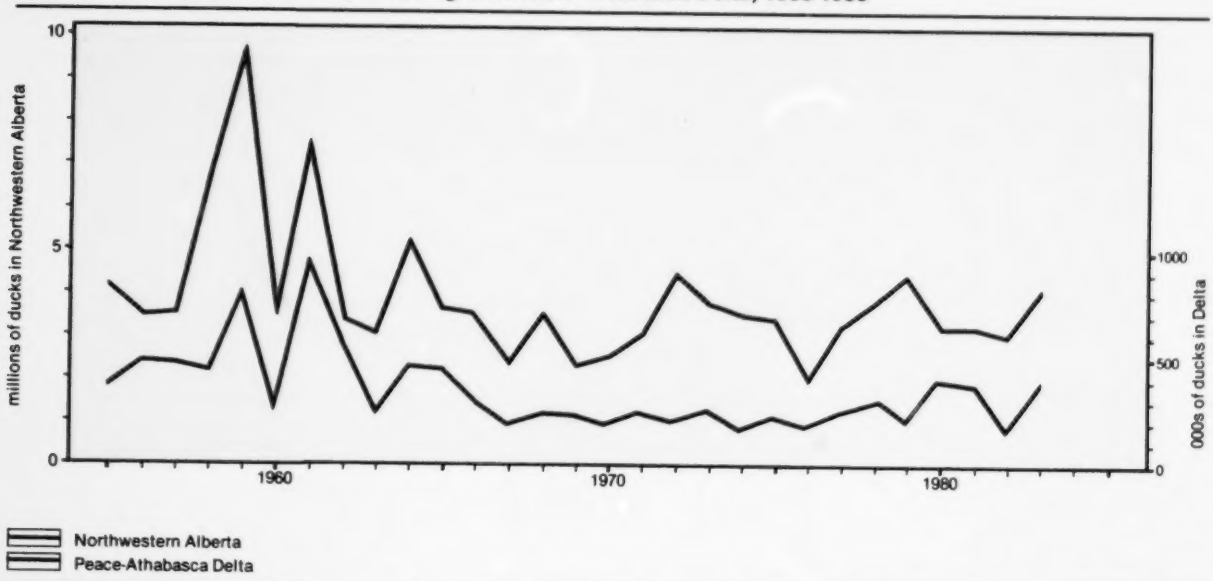


Source: U.S. Fish and Wildlife Service, May survey.

Figure 6.3
Index of Ponds on the Canadian Prairies, 1961-1985

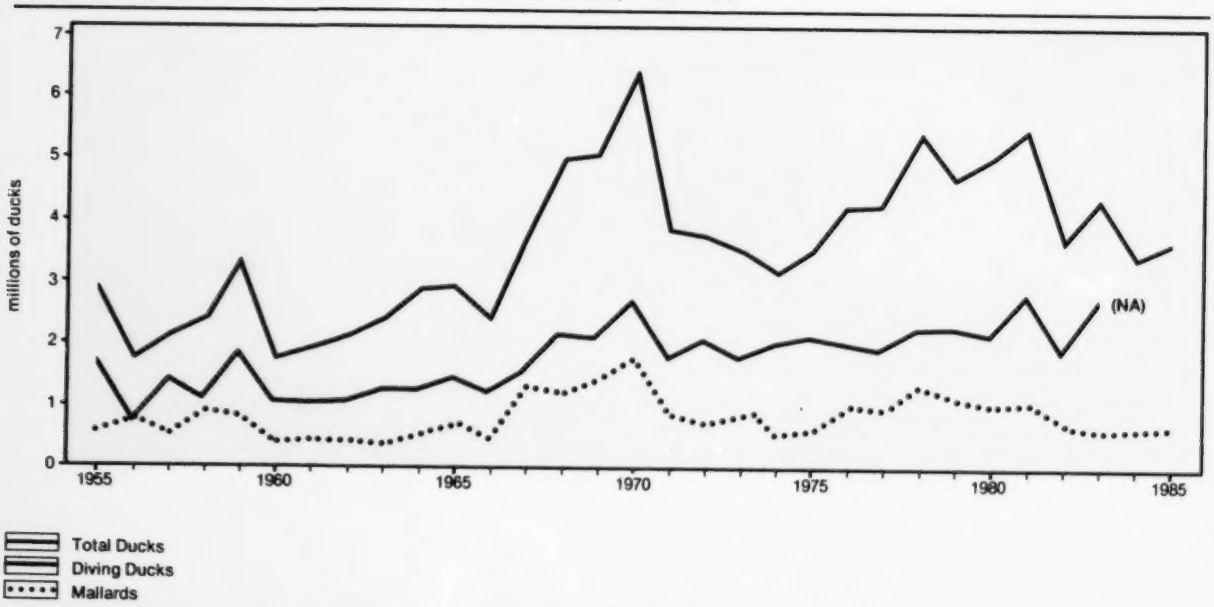
Source: U.S. Fish and Wildlife Service, May survey.

Figure 6.4
Ducks in Northwestern Alberta, including the Peace-Athabasca Delta, 1955-1983



Source: U.S. Fish and Wildlife Service, May survey.

Figure 6.5
Breeding Ducks in the Western Part of the Boreal Shield, 1955-1985



Source: U.S. Fish and Wildlife Service, May survey.

Athabasca Delta, the most important concentration in the region (plotted on a different scale). The ecology of the delta was greatly affected by construction, completed in 1968, of the Bennett Dam on the Peace River, far upstream in British Columbia. In the year immediately following, duck numbers in the delta remained low (around 200 000), while numbers elsewhere in northern Alberta were increasing. Since 1975, the duck population of the delta has shown some recovery towards the earlier levels, but ducks have not done as well as the other occupants of the region.

Taiga Plain

Aside from its rich and diversified population of furbearers, this region is also home to the wood bison, now on the endangered species list (Table 6.6). Before the turn of the century, wood bison were abundant in northern Alberta and the southern Mackenzie District, including the region of the present-day Wood Buffalo National Park and the adjacent salt plains east of the Slave River Lowlands Park. Wood Buffalo National Park was created in 1922 to protect the bison population, which by then had been reduced to between 1 500 and 2 000 animals.

From 1925 to 1928, 6 700 plains bison were transported north to the park where they interbred with the wood bison. The hybrids became diseased (with brucellosis, tuberculosis and anthrax), and a series of reduction slaughters within the park was undertaken in the hope of eradicating these diseases. Other catastrophes (e.g., mass drownings in 1962 and 1967, as a result of the breakup of river and lake ice on spring migration routes) further reduced the bison population. Thus, more than half a century after conservation measures were initiated, the bison has yet to recover to a healthy stock. In 1984 the bison population was estimated to be less than 4 000 within the park and 200 in the Slave River lowlands. These stocks are mainly hybrid. A pure wood bison stock in the Fort Providence area on the western shores of Great Slave Lake, started with 18 wood bison captured in the northwest corner of Wood Buffalo National Park in 1963, has grown to about 1 000 animals, forming the largest reservoir of this sub-species.

The whooping crane also finds sanctuary in Wood Buffalo National Park (Table 6.10). This endangered species is recovering slowly, although the total population is still so small that it will remain precarious for many years.*

Table 6.10
Whooping Crane Population in Wood Buffalo National Park, 1941-1985

Year	Adults
1941	15
1954	21
1960	36
1965	44
1980	76
1982	73
1983	75
1984	75
1985	85

Source: J.C. Lewis, *Whooping Crane Recovery Plan, 1985*, Draft Report, U.S. Fish and Wildlife Service, Region 2.

Taiga Shield

This region is separated into two sectors by Hudson Bay. Fur trapping is important here, but it is the migratory barren-ground caribou and the muskox in the western part of this zone that are of special significance. (There is a more detailed discussion on caribou later in this section.)

Between 1862 and 1971 at least 15 000 muskoxen were slaughtered for skins, reducing the mainland herd to small groups. In 1927 the Thelon River area was set aside as a game sanctuary in an attempt to conserve the largest remaining population, a group of about 250 animals. Muskoxen have subsequently rebounded both on the mainland and in the arctic islands. By 1937, there were 300 animals in the sanctuary and 500 elsewhere on the mainland. In 1982 the estimate for the total mainland population was 15 000 individuals, of which 1 000 were in the Thelon Sanctuary.

Boreal Shield

The vast forestlands of the Boreal Shield, a habitat for deer, moose, woodland caribou, black bear and wolves, is a readily accessible recreational hunting territory for the urbanized populations of the Mixed-Wood Plain. In addition, the fur-bearers of this zone are a source of livelihood for many trappers and hunters. Proximity to the centres of high population has made this ecozone vulnerable to wildlife harvest pressures.

With its many lakes, ponds and swamps, the Boreal Shield is an important breeding ground for Canadian waterfowl. Productivity is on the order of two ducks per square kilometre per year (as opposed to 50 on the prairies in good years); nevertheless, over an area of 1.8 million square kilometres, annual duck production averages 3.6 million individuals. Waterfowl counts taken on the breeding grounds north of Lake Winnipeg and west to the Saskatchewan boundary are shown in Figure 6.5. Here, too, there have been con-

*Cranes do not breed until they are at least five years old and rear but one young per pair each year. Population recovery is slow. Attempts are now being made to establish new breeding grounds in the United States (Idaho), and another project is using birds reared in captivity.

siderable fluctuations in breeding populations. Over the period 1955-1985, the number of breeding ducks fluctuated between 1.7 million and 6.25 million ducks, though with an upward trend, especially for diving ducks. Mallard numbers peaked in 1970, at 1.55 million. In recent years numbers have fallen steadily, probably as a result of hunting pressure in the United States rather than events on the breeding grounds. No long runs of data on waterfowl numbers are available for the massive extent of the Boreal Shield, which runs from the Manitoba border to the Atlantic coast. Data on hunting in eastern Canada (kill per unit effort) suggest that total duck numbers have remained fairly steady and, in some areas, have increased.

Hudson Bay Plain

This region is the world's southerly habitat of the polar bear (*Ursus maritimus*) which ranges in large numbers throughout the coastal zone. Approximately 75 per cent of the world population of polar bears is found in Canada, and this area has the heaviest concentration. (See discussion on polar bears at the end of this section.)

The coastal areas of the Hudson Bay Plain, with wide bands of emergent vegetation, provide ideal nesting conditions for lesser snow geese and, inland, for Canada geese. The estuaries of the rivers entering the south and west sides of James Bay provide extremely important stopover areas for a large number of species, including lesser snow geese, Canada geese, Atlantic brant, and many species of duck and shore bird, on their fall migration from northern breeding grounds to wintering areas to the south.

Over the period 1973-1985, the distribution of lesser snow geese in the Arctic has shifted substantially, decreasing in western Hudson Bay and increasing in southern Hudson Bay, the Queen Maud Gulf and Jenny Lind Island. During this period, changes have also occurred in the Baffin Island and Southampton Island populations. The total goose population has continued to expand.

Mixed-Wood Plain

Wildlife concerns in this region are related primarily to loss of habitat, or habitat rehabilitation, and to pests such as woodchucks, coyotes, cottontails, wolves and foxes, on farmlands. Fragmentation of habitats, exposure to contaminants and the danger posed by high-density road traffic are just some of the examples of the stresses experienced by wildlife. To survive, wildlife needs to adapt to this constantly changing landscape. A particularly extreme example is the adaptation of wildlife to urban environments. Although this phenomenon has been observed in several ecozones, it is particularly pronounced here.

The loss of land to subdivisions, roadways, industrial estates, and other uses has led, in some cases, to adaptation by small and medium-sized mammals (groundhogs, skunks, raccoons, foxes, rabbits) through survival strategies for feeding and breeding in urban parks, ravines, vacant land and backyards. Others, largely scavenger birds, have discovered an easy food source in urban refuse (e.g., ring billed gulls). These species join the traditional urban pigeons, sparrows, starlings, squirrels, mice, and rats, as well as a growing pet population, to make up an animal density far greater than that normally found in nature. The attractive feature of the urban landscape is not the noise, the pollution, or the human presence, but rather the ready availability of food in the form of urban garbage dumps.

A reverse process of ruralization is demonstrated in the adaptation of escaped or abandoned domestic pets to survival in the wild. Feral dogs travelling in packs have emerged as a menace to the deer population in eastern Ontario and western Quebec, especially during the period of deep snow in early spring.

Among birds, the ring billed gull is the classic example of a species that has discovered the city as a hospitable habitat. Fifty years ago, ornithologists were predicting the gradual extinction of the ring billed gull (which seemed unable to withstand human pressure) and the continued pre-eminence of the herring gull. In the past two decades, throughout the lower Great Lakes and St. Lawrence River region, ring billed gulls have learned to subsist on rodents and urban garbage as well as, or instead of, their traditional diet of freshwater fish. Over the past 12 to 15 years, the ring billed gull population around the Leslie Street Spit (created out of fill) in Toronto has increased from 20 pairs to an estimated 80 000 pairs. Elsewhere, colonies in the shadow of downtown areas have been

Table 6.11
Annual Production of Major Fur-Bearers and Total Population Estimates for Major Fur-Bearers in the Atlantic Maritime Ecozone, 1981-82

Species	Annual Production[1] (000s)	Population (000s)
Beaver	15.4	59
Mink	7.2	18
Muskrat	96.6	304
Raccoon	18.8	42
Red fox	7.1	33
Wildcat	2.3	14

[1]Production calculated as the sum of the reported kill in Prince Edward Island, Nova Scotia and New Brunswick.

Source: Statistics Canada, *Fur production, Season 1981-1982*, Statistics Canada Catalogue 23-207.
Department of Industry, Trade and Commerce, *Report on the Status of Canadian Wildlife used by the Fur Industry* (Ottawa: Minister of Supply and Services, 1978).

increasing at a rate of 10 per cent per year. The gulls are now establishing new breeding colonies, and there is as yet no indication of a levelling off in their population growth.

The northern fringe of the ecozone retains some wilderness characteristics, and hunting and trapping are still carried out. Some fur-bearers that were once over-harvested have recovered (e.g., the fisher, *Martes pennanti*).

This ecozone is also of major importance for migrating waterfowl and other species, though much less so in its present heavily developed state than it must have been prior to European settlement.

Atlantic Maritime

This region contains many important fur-bearers. Among the principal species are beaver, red fox, muskrat, raccoon and mink. Data on recent harvest and population estimates for the major fur-bearers of the Atlantic Maritime ecozone are given in Table 6.11.

Bonaventure Island has one of the largest gannet colonies on the Atlantic Ocean. The colony has been monitored intermittently since 1887, providing a long time series on population. The colony was heavily exploited in the early part of the nineteenth century, and the slaughter of birds and egg poaching took a heavy toll. Under protection afforded by the *Migratory Birds Convention Act* of 1917, there was substantial recovery. A setback in gannet populations is attributable to reproductive failures caused by the intake of pesticides, particularly DDT. The use of the pesticide DDT in the New Brunswick forests was considered the primary cause of reproductive decline, and subsequent reduction and elimination of the use of DDT have allowed the rate of reproduction to return to pre-DDT levels.

The number of white-tailed deer (*Odocoileus virginiana borealis*) in this ecozone has fluctuated widely, at times disappearing entirely, to reappear later by natural immigration into New Brunswick about 1818. White-tailed deer were reintroduced into Nova Scotia after 1890 and into Prince Edward Island in 1949. Except for the small group still extant in western Prince Edward Island, in the other two provinces deer numbers are large and the population is stable. Because they are harvested at maximum sustainable yield and there has been a decline in the carrying capacity of the habitat, increased productivity of the population is not possible. The number of moose (*Alces alces americana*) has also fluctuated widely. It was reintroduced into Cape Breton Island in 1947 and is rebounding from population lows early in the century to healthy populations at present in the rest of Nova Scotia and New Brunswick.

The woodland caribou, once numerous in this ecozone, disappeared some decades ago, possibly from a combination of increased hunting and the lungworm (*Parelaphostrongulus tenuis*), which is transmitted by the white-tailed deer. This parasite is fatal to caribou but not to deer. To rectify this situation and to make use of the caribou range of the Cape Breton Highlands, caribou from the George River herd in Quebec were transplanted to the Highlands in 1975. These animals were released after months of preconditioning to acclimatize them to new surroundings. They did not survive, apparently as a consequence of illegal hunting.[19]

Arctic

Southern Arctic

This ecozone includes the calving grounds of six major caribou herds: the Porcupine herd on the North Slope (on the Alaskan border); the Bluenose herd in the vicinity of Bluenose Lake; the Bathurst herd near Bathurst Inlet; the Beverly herd around Beverly and Aberdeen Lakes; the Kaminuriak herd in the vicinity of Kaminuriak Lake; and the George River herd in northern Quebec and Labrador.* In addition, reindeer (*Rangifer tarandus tarandus*), an exotic sub-species brought to the Mackenzie Delta from Norway via Alaska in 1935, is loose herded on the Tuktoyaktuk Peninsula. About 16 000 animals occur there, and another 287 are found on the Belcher Islands in Hudson Bay, where they were introduced in 1978. All caribou herds summer on the tundra, with the exception of the Porcupine herd, which moves, after calving, eastward along the North Slope and south into the taiga. Population trends are given in a separate section on caribou later in this chapter.

The Mackenzie River Delta is famous for its production of waterfowl, despite the fact that it lies well north of the Arctic Circle. Its nesting waterfowl include several species of geese and ducks as well as tundra swans. The breeding populations of ducks (1955-1984) are shown in Figure 6.6. Although the number of diving birds is highly variable, within the range of 50 000 to 210 000, it was the dabbling ducks, especially pintails, that produced the peaks in 1958-1962 and 1980.

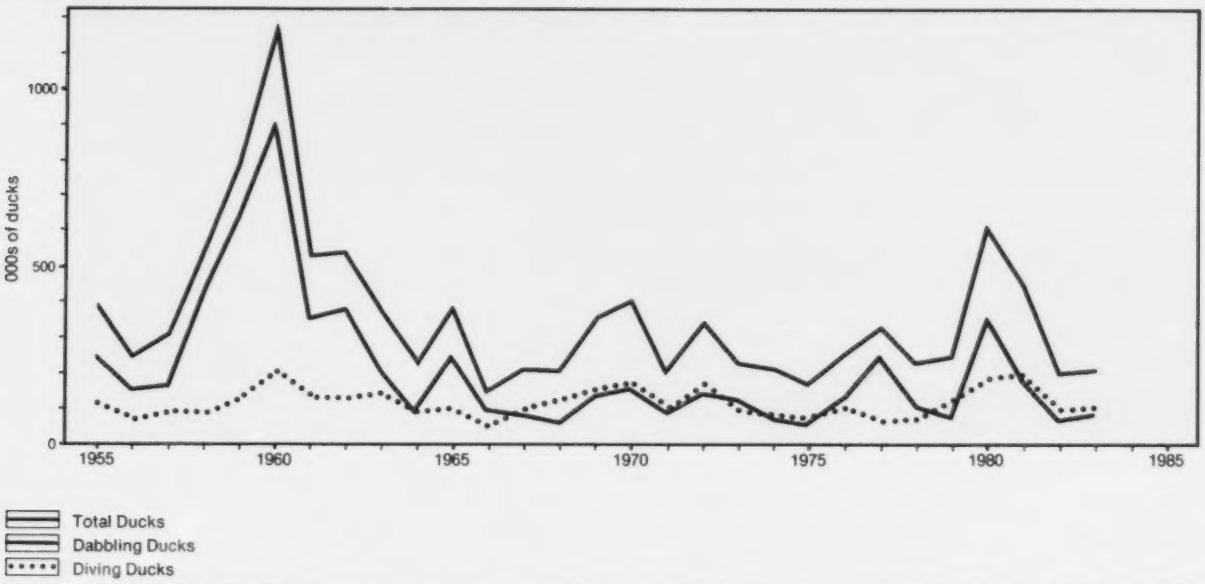
Northern Arctic

Because of cold temperatures, thin soils and low levels of precipitation, only about 10 per cent of this area is covered by vegetation. There are more than 200 species of flowering plants, and there are even trees in sheltered areas, though not trees of the kind familiar in temperate Canada. Dwarf willow may reach a hand's length in height, with a trunk the diameter of a finger, and may have an age of 100 years.

The Northern Arctic ecozone provides an important habitat for muskox. Protected since 1971, muskoxen have rebounded from approximately 10 000 in 1960[17] to 45 000 individuals in 1983.[12] The major increase has been on Banks Island. Periodic severe

*The George River herd are woodland caribou, whereas the others are barren-ground caribou.

Figure 6.6
Breeding Ducks in the Mackenzie Delta, NWT, 1955-1983



Source: U.S. Fish and Wildlife Service, May survey.

weather leading to significant dieoff is a part of the history of this species; Melville Island and Bathurst Island provide two such examples.[15,6]

Peary caribou and polar bear are also major inhabitants of the Northern Arctic ecozone, and both populations are reported to be in a somewhat precarious state.

In the relatively well vegetated parts of the Northern Arctic ecozone there are groups of breeding geese, especially brant, greater snow geese in the east, and lesser snow geese on Banks Island and, increasingly, on the lower tier of islands south of the Northwest Passage. Although the colonies of lesser snow geese are large, the other geese are more widely dispersed, and many occupy some of their breeding places only intermittently, because the growth of sedges and grasses, their main source of food, is limited by low levels of sunlight.

The region provides the world's only nesting grounds for greater snow geese, most of which nest on Bylot Island and northern Baffin Island, although some can be found up to the northern tip of Ellesmere Island. Owing to the harsh climate and conditions, there is partial or complete reproductive failure in about one year out of three. Nevertheless, the population increased from about 2 000 in the early 1900s to 60 000 in 1950, and over 200 000 were reported in the spring of 1984.

Mammalian habitat is limited, as mountain glaciers take up a large part of this ecozone. In nonglaciated parts, the muskox is the dominant herbivore. It exists in small numbers on the Hazen Plateau,[5] an area in the proposed Ellesmere National Park, and in relatively large numbers in the Eureka Sound area.[17] On the west side of Ellesmere Island, one of the most biologically interesting events is the periodic population fluctuation of Arctic hare (*Lepus arcticus*).

Caribou

Caribou once ranged over almost all of Canada — woodland caribou in the south, and barren-ground and Peary caribou in the arctic islands. Although the range of woodland caribou is now very much reduced,* they are still present from Newfoundland (although extirpated in Nova Scotia) to British Columbia and the Yukon. Table 6.12 shows estimates of woodland caribou populations by province, along with recent trends in those populations.

The woodland caribou was reduced in numbers and range in the late nineteenth and early twentieth centuries by disease, predation and excessive hunting. Currently, population trends vary with the region.** In northern Quebec and Labrador and Ontario there have been increases, particularly in the George River herd, which has grown rapidly over the past quarter century and is now estimated to be in

*They are now absent south and east of the St. Lawrence River and Great Lakes except for a small herd on the Gaspé Peninsula. From Quebec to British Columbia the caribou range is substantially reduced along its southern periphery, and southernmost populations tend to be reduced and scattered.

**Woodland caribou in the forested areas form small groups and therefore are difficult to count. The George River woodland caribou are found in the tundra and form large herds similar to the barren-ground caribou.

Table 6.12
Estimated Number of Woodland Caribou in Canada, 1985

	Recent Trend	Numbers (000s)
British Columbia	Stable or decreasing	5.7
Alberta	Decreasing	2.3
Saskatchewan	Decreasing	2.5
Manitoba	Unknown	5.0
Ontario	Stable or increasing	8.4
Quebec/Labrador, south	Decreasing	8.9
Quebec/Labrador[1]	Increasing or stable	600.0
Leaf River	Unknown	68.0
Torngat Mountains & Koruc River	Unknown	12.5
Newfoundland (Island)	Increasing	32.1
Yukon	Unknown	24.1
Northwest Territories	Unknown	3.5
Total		773.0

[1]Includes George River herd.
Source: Environment Canada, Canadian Wildlife Service, Western and Northern Region, Edmonton.

excess of 600 000 individuals.* In Alberta and Saskatchewan populations are decreasing. The distribution of woodland caribou for all regions is provided in Figure 6.7.

Today, with the exception of the Bluenose herd, herds of barren-ground caribou appear larger than they were in the mid-1950s. Table 6.13 shows the results of recent aerial surveys and photo interpretations. Figure 6.7 shows the current distribution of major barren-ground caribou herds.

Polar Bear

The polar bear is found along the shores of the Arctic Ocean, Hudson Bay and James Bay. Table 6.14 provides population estimates for the management zones shown in Figure 6.8.

Canada's harvest and incidental kill (including natural deaths) is monitored through participation in the International Agreement for the Conservation of Polar Bears; the export of hides is monitored through the Convention on International Trade in Endangered Species. For those management zones for which population estimates are available, the total kill in the 1982-83 season was 6.1 to 6.6 per cent of the population, a range well within the limits of a sustainable yield.

*This is Canada's largest caribou herd. In the fall of 1984 up to 10 000 animals drowned while crossing the Kaniapiskau River on the migration route to their wintering grounds.

Table 6.13
Estimated Number of Barren-ground Caribou in Canada

Herd	Survey Date	Recent Trend	Numbers (000s)
1 Porcupine	1983	Increasing	150
2 Bluenose	1983	Unknown	65
3 Bathurst	1984	Increasing	385
4 Beverly	1984	Increasing	335
5 Kaminuriak	1983	Increasing	230
6 Wager Bay/Melville	1983	Increasing	120
7 Boothia	?	Increasing	1.1
8 Baffin	1984	Increasing	100
9 Southampton/Coats	1978/84	Increasing	3.2

The range of each herd is shown in Figure 6.7. The George River herd (woodland) is number 10.
Source: T.M. Williams and D.C. Heard, "World Status of Wild *Rangifer* Populations", Poster at Fourth International Reindeer/Caribou Symposium, Whitehorse, Yukon.

Table 6.14
Polar Bear Population

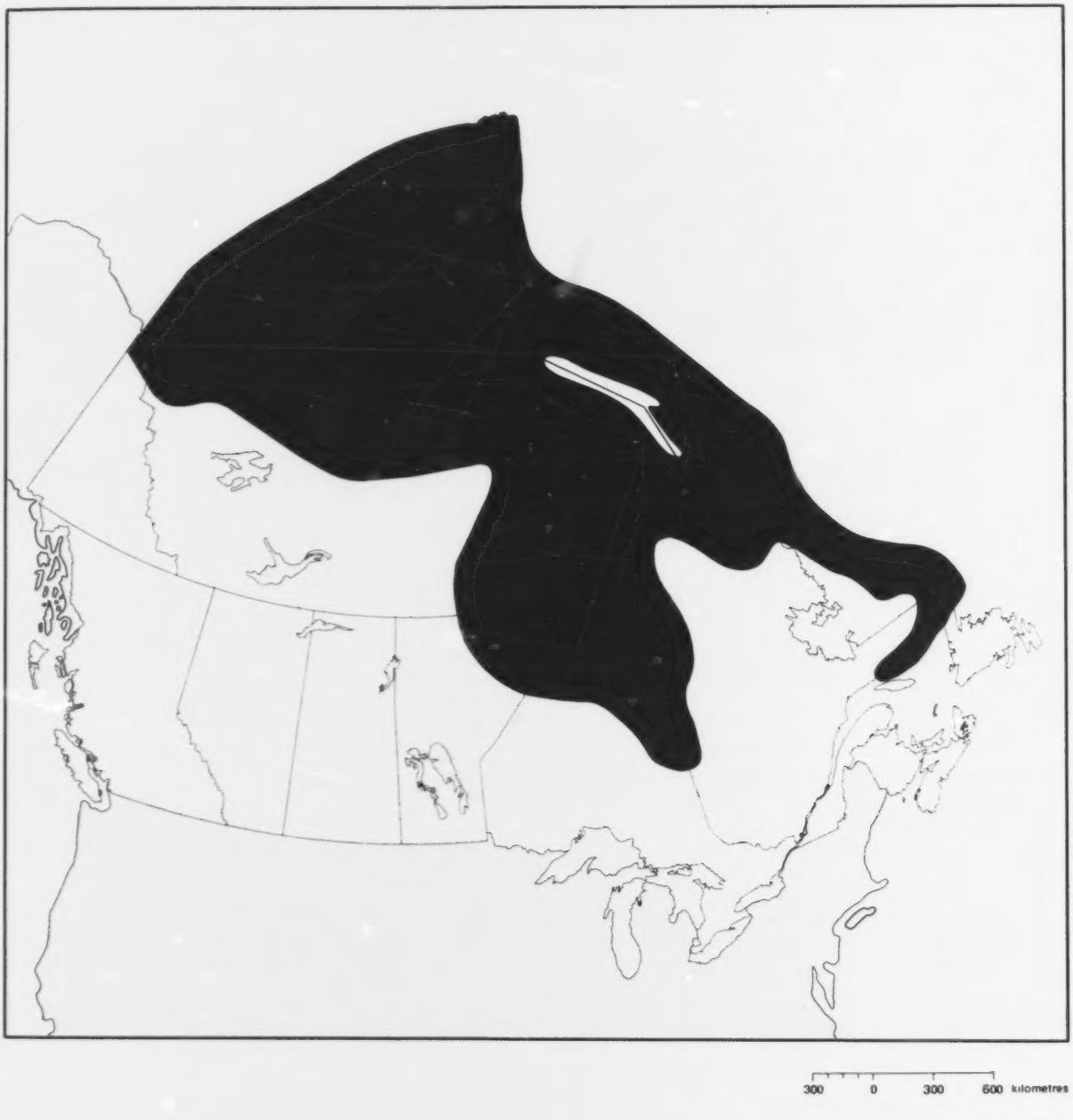
Management Zone[1]	Population Estimate 1981[2]	Hunting Kill	Incidental Kill[3]	Hunting Quota
A[a]	1 500-1 800	54	11	95
A[b]	NA	15	0	25
A[c]	250	35	0	30
B	75	15	0	5
C	75	141	6	137
D	700	98	11	99
E	1 100	89	11	81
F	1 800-2 000	99	6	104
G	1 800-2 000	8	0	12
H	1 800	92	4	97
Canada Total	9 100-9 800	646	49	685

[1]Locations of management zones are shown in Figure 6.8.
[2]Estimates are based on mark and recapture in 1981.
[3]Incidental kill includes problem kill, handling death, illegal kill, unknown source of kill and natural deaths.
Source: Environment Canada, Canadian Wildlife Service, Edmonton, unpublished data.

Figure 6.7
Distribution of Caribou

Source: Environment Canada, Canadian Wildlife Service, unpublished information.
Indian and Northern Affairs Canada, Northern Environment Directorate.
Government of Quebec, Ministry of Recreation, Hunting and Fishing.
Government of the Northwest Territories, Department of Renewable Resources, Division of Wildlife Management, Yellowknife.
Government of Yukon, Department of Renewable Resources.

Figure 6.8
Distribution of Polar Bear



Source: Environment Canada, Canadian Wildlife Service, Edmonton, unpublished data.

INFLUENCES ON THE STATE OF WILDLIFE

Influences on the distribution and abundance of Canadian wildlife include changes in the quality and quantity of available habitat, hunting and trapping, climate, pollution, disease and the introduction of exotic species. A good many of the species discussed above have been subject to one or more of these stresses, which may act singly or synergistically.

Changes in Habitat

Dramatic transformations of the landscape inevitably accompany human settlement and development and have considerable influence on wildlife habitat (see Table 6.15). Examples of habitat transformation are discussed in this section.

Agriculture

In the prairies and parkland belt, immigration policies at the turn of the century encouraged homesteading. The aspen parkland belt came under intensive cultivation; its rich soil and moist climate made it even better suited to agriculture than the grasslands to the south.

Intensive use of the parkland for agriculture reduced the original aspen stands to patches. Less than 40 per cent of the original parkland now remains in Saskatchewan, and less than 20 per cent remains in Alberta. This loss has reduced suitable habitat for large and small mammals and increased the need for these animals to migrate between small patches of the original parkland.

In the Prairie ecozone, the use of grasslands for crop cultivation and large-scale cattle ranching since the 1870s has led to the gradual restriction and, in some cases, the total elimination of these lands as viable habitats for large mammals. Herds of plains bison, which may once have numbered 2 million animals, are gone, and antelope, which once numbered in the hundreds of thousands, have been reduced to 10 000 to 20 000. Currently, antelope herds are considered to be in a healthy state and are increasing.

In many regions of Canada, wetlands have been drained for agriculture, especially in the Prairie ecozone, the Mixed-Wood Plain and the Pacific Maritime ecozone. In western Canada, approximately 1.2 million hectares of wetland habitat have been converted to agricultural use. These losses of wetland habitat to agriculture over the past century have been progressive and severe, occurring in virtually all parts of the prairies.[16] Regional losses have been high. For example, there has been a 57-per cent decline in original wetlands in the Minnedosa region of Manitoba. In southern Saskatchewan, 84 per cent of the wetlands have been altered in some way by human activities.[8]

In southern Ontario, the expansion of agriculture over the past century has led to the loss of 70 per cent (more than one million hectares) of the pre-settlement wetland area through land drainage and filling and dyking of shoreline marshes.[2] These wetlands provided migration stopping places for millions of geese and ducks and thousands of whistling swans.

In the east Kootenays of British Columbia, most land has been used as open range for cattle. Here cattle compete with Rocky Mountain bighorn sheep for winter range. Intensive grazing by cattle and wild ungulates has altered plant communities of the east Kootenays and interior plateau so that they resemble the less developed earlier stages of succession.[4]

Decreases in available habitat in some areas are partially balanced by increases in others. The abandonment of marginal farmland, especially in the Atlantic Maritime ecozone and Mixed-Wood Plain, and subsequent reforestation have provided wildlife with an opportunity to repopulate these areas.

Forestry

Logging has resulted in enhanced habitat for some species (those requiring new growth for food) while causing deterioration of habitat for others. In the Montane Cordillera, clearcutting is beneficial to moose, deer and elk, but detrimental to mountain or woodland caribou, which feed primarily on arboreal lichens, and to woodpeckers and marten, which prefer a mature forest. Forest regeneration in general has a healthy effect on ungulate populations, especially when the tree species most likely to emerge is aspen (the preferred species for both moose and deer). Coniferous plantations, however, tend to reduce wildlife productivity as they provide little in terms of food. Nor do they create a suitable undergrowth habitat for small animals.

Hydro-electric Power

The impounding of large water areas for the production of hydro-electricity has been extremely destructive of wildlife habitat, particularly in the northern fringes of the Boreal and the Taiga Shields, where bottom lands (i.e., valley floors) are the only available soils productive enough to provide vegetation. Reservoirs often flood vast areas — sometimes hundreds of square kilometres — that thereafter can support little terrestrial wildlife.

With time, some flooded areas can be transformed into habitat suitable for beaver and muskrat. In many cases, however, even this is impossible because the pattern of seasonal drawdown causes large changes in water levels at inappropriate times. Here we cite several of numerous examples of this sort.

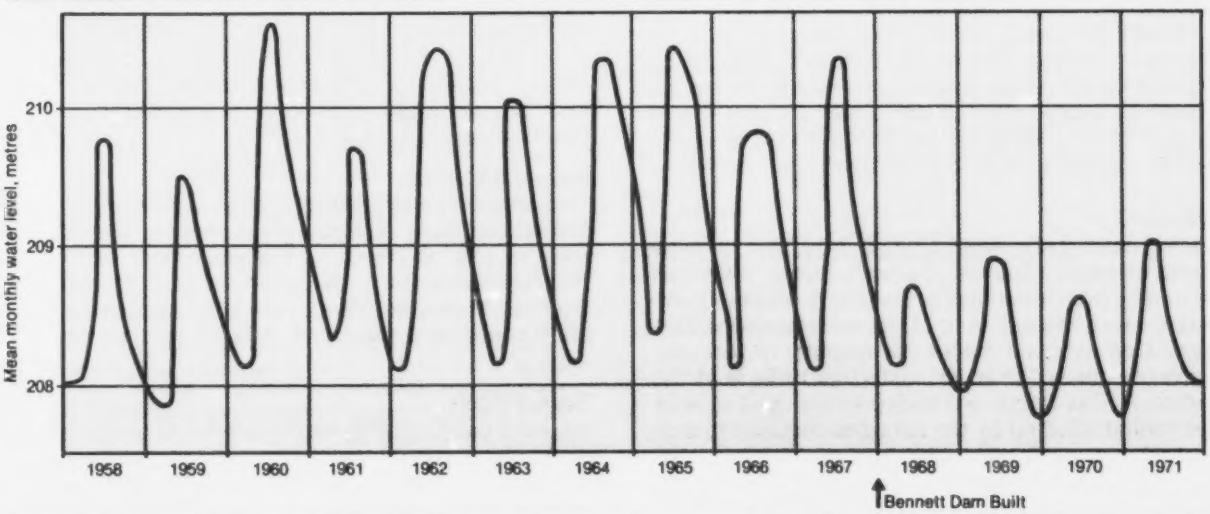
The Bennett Dam (completed in 1968 on the Peace River) significantly altered the character of the Peace-Athabasca Delta. During the period when the headpond (Williston Lake) was filling, a substantially reduced flow in the Peace River lowered the average water level in Lake Athabasca (1968-1971, Figure 6.9).

Table 6.15
Current Influences on Canadian Wildlife

Ecozone	Land Use Change				Hunting/ Trapping	Pollution[3]	Disease	Exotic Introductions[4]
	Agriculture	Forestry	Resource Development[1]	Other[2]				
Tundra Cordillera				■	■			
Boreal Cordillera			■		■			■
Pacific Maritime	■	■			■	■		■
Montane Cordillera	■	■	■		■			■
Boreal Plain	■	■	■	■	■	■		
Taiga Plain			■	■	■	■	■	
Prairie	■				■			■
Taiga Shield			■		■	■		
Boreal Shield		■	■		■	■		
Hudson Bay Plain					■			
Mixed-Wood Plain	■					■		■
Atlantic Maritime	■	■			■	■		■
Southern Arctic				■	■	■		■
Northern Arctic					■	■		
Arctic Cordillera			■		■	■		

[1]Includes larger dam construction, mining development.
[2]Includes transportation corridors, seismic lines, power lines.
[3]Includes oil, SO_2 gas, mine residues.
[4]Includes consideration of birds and mammals only.

Figure 6.9
Water Levels in Lake Athabasca, 1958-1971
(before and after construction of the Bennett Dam)



Source: Information Canada, *Peace Athabasca Delta — A Canadian Resources Summary Report, 1972.*

The immediate effect was to drain the perched basins, permitting the growth of willow trees in previously productive marshland areas. Approximately 36 per cent of the perched basin shorelines disappeared between 1968 and 1971.* These basins have subsequently become overgrown with vegetation, and their suitability for breeding ducks has been greatly diminished, even after slightly higher water levels were restored. The immediate reduction in duck production was in the neighbourhood of 20 per cent. Muskrat were also affected adversely, and the commercial goldeye fishery was eliminated (see also Chapter 5).

The development of hydro-electricity in the Taiga Shield has produced by far the largest transformation in wildlife habitat in this region. Two of the three hydro-electric facilities (Snare River and Taltson River) are relatively modest; they were created to supply power to Yellowknife and Pine Point respectively. The third, the huge James Bay hydro-electric project on the La Grande and Eastmain Rivers, has flooded nearly one-quarter of the eastern portion of this region. As a consequence, there have been significant losses of moose and fur-bearers,[19] a source of livelihood for the local Cree. A major portion of the compensation package awarded to these people was intended to offset losses resulting from flooding of traditional hunting and trapping lands.

Transportation and Other Corridors

The road-building program in Canada's northland and the extension of the road network associated with mining, forestry, and hydro-electric development have increased the access of hunters to previously isolated wildlife habitats. In the Boreal Plain, new roads have contributed to hunting stress on woodland caribou herds, which once were numerous but are now, with a few exceptions, considered threatened. In the central part of the Tundra Cordillera, the Dempster Highway gives increased hunting access to wintering caribou and other wildlife.

Seismic lines traverse the Cameron Hills in Northern Alberta. These corridors (a feature of oil exploration activity) promote new growth in the mature forest, a change unfavourable to mammals that need mature forest habitat but favourable to those requiring new growth for food and cover (e.g., moose).

Mining

Mining activity effectively removes and disturbs large tracts of wildlife habitat. The area directly disturbed by mining and oil and gas extraction is small by comparison with the vastness of the surrounding wilderness. One estimate places the quantity of land disturbed by mining in Canada in the late 1970s at 51 000 hectares. This figure is dwarfed by the area of wildlife habitat affected by the activities required to support mineral and fossil fuel extraction. These include the development of town sites, construction of transportation routes (roads, railways, pipelines), other infrastructure (e.g., hydro-electric power), waste disposal and mining exploration.

These cause environmental transformations in northern ecosystems that are well beyond those normally associated with similar activities in the settled parts of the country.

Some of these transformations pose unusual hazards for wildlife. For example, the tailing ponds of the Athabasca Tar Sands consist of oily residues. These ponds are located near the Athabasca River, south of Lake Athabasca, and are several square kilometres in area. They are warmer than the surrounding natural ponds and are open later in fall and earlier in spring and therefore attract migrating waterfowl. Birds alighting here risk drowning (because of the oil), and many become coated with oil residues.

An estimate of the pervasive effects of northern development projects on wildlife habitat in just one ecozone, the Boreal Plain, is shown in Table 6.16. The calculation considers areas affected by mineral and oil extraction, pulp and paper mills, hydro-electric power development, transportation networks and land set aside for military purposes (the Primrose Lake Bombing and Gunnery Range). The total area of lost habitat or reduced wildlife productivity attributable to these activities was calculated at 68 000 square kilometres, an area slightly smaller than New Brunswick. Over 80 per cent of the area affected was accounted for by four large-scale oil and gas development projects: Swan Hills (22 000 km^2); Rainbow Lake (10 000 km^2); the Fort McMurray Tar Sands Operation (20 000 km^2); and the Peace River Heavy Oil Project (5 000 km^2).

Hunting and Trapping

Hunting and trapping place pressure on all accessible game species. Table 6.17 provides data on the pelts taken in the 1982-83 season; these were well in excess of 2.8 million fur-bearers. Table 6.18 provides data by province on the large mammal sport kill and kills by Native people in 1983. Some examples are provided below.

Boreal Cordillera

This area contains the major range of Stone's sheep (valued principally as a trophy specimen by sport hunters), as well as mountain caribou, moose and grizzly. These mammals are under hunting pressure in Spatsizi Provincial Park, where sport hunting is encouraged as a means of bringing revenue to the area.

Boreal Plain

Here big game hunting has centred on moose (*Alces alces*), the dominant ungulate, as well as on woodland and barren-ground caribou. Hunting by Native people (which is not regulated by licence) includes the Beverly herd of migratory barren-ground caribou. The

*Perched basins are shallow water bodies that are drained when water levels decline.

Table 6.16
Wildlife Habitat Affected by Human Activities in the Boreal Plain

Influence	Effect	Estimated Area Affected (km^2)
Swan Hills Oil and Gas	Wilderness aspect of Swan Hills biotype destroyed	22 000
Tar Sands Project at Fort MacMurray	Open-pit mining; incremental denudation of wildlife habitat; ducks killed in wastewater ponds	20 000
Rainbow Lake Oil and Gas	Originally frontier development; now fully in production — increased accessibility by hunters	10 000
Heavy Oil Project at Peace River	Steam extraction similar to Cold Lake Project	5 000
Primrose Lake Bombing and Gunnery Range	Fishing and trapping areas lost	3 750
Bennett Dam and Williston Lake	Timber lost; downstream water regime changed drastically	1 500
Hinton Pulp and Paper Mill	Wildlife production reduced for 10 to 15 years	1 000
Prince Albert Pulp and Paper Mill	Wildlife production reduced for 10 to 15 years	1 000
Cold Lake Heavy Oil Project	Industrial complex in semi-wilderness area	500
Wabamun Lake Power Facility	Surface coal mining	500
Cache Creek Coal Mines	Provides accessibility to wilderness hunting	500
Swansons Lumber Timber	Clearcutting — regeneration slow	500
Ancillary Services, Road and Railbeds	Road kills of wildlife and increased accessibility	500
Major Townsites or Settlements	Wildlife depletion within accessible range	500
Grand Rapids Dam and Cedar Lake	Ranchers and farmers lost land; muskrat trapping greatly reduced	480
Cluff Lake Uranium Mine	Open-pit; buffer zones	100
Alberta Grand Trunk Pipeline	Right-of-way kept clear for maintenance	400
Squaw River Rapids Dam and Tobin Lake	Trappers lost trap lines; merchantable timber lost	400
Rabbit Lake Uranium Mine	Kept clear of people and wildlife	100
Key Lake Uranium Mine	Kept clear of people and wildlife	100
Total area affected (square kilometres)		68 830

Source: Thurlow and Associates, "Final Report on the Wildlife Component for the 15 Ecozones — State of the Environment Report", 1984.

Table 6.17
Fur-Bearers in Canada: Pelts Taken, 1982-83[1]

Species/Sub-species	Number of Pelts
Badger	4 333
Black bear	2 464
Grizzly bear	12
Polar bear	227
Beaver	335 711
Cougar	15
Coyote	73 594
Ermine	42 925
Fisher	21 005
Blue fox	187
Red fox	87 821
Silver fox	978
Arctic fox	14 345
Other foxes	6
Lynx	29 533
Marten	139 638
Mink(wild)	79 705
Muskrat	1 443 035
Otter	18 450
Rabbit	243
Raccoon	158 369
Seal[2]	*
Skunk	1 004
Squirrel	348 685
Bobcat	2 300
Wolf	6 983
Wolverine	1 030
Total	2 812 598

[1]Winter is the trapping season in most cases.
[2]Seal pelts cannot be reported because data are confidential.
Source: Statistics Canada, *Fur Production 1982-1983*, Catalogue 23-207.

Table 6.18
Sport and Native Hunting Kills of Large Mammals, 1983
(by province)

Province/Territory	Moose	Deer	Caribou	Wapiti	Antelope	Mountain Sheep[1]	Mountain Goat	Bison[2]	Bear[3]	Mountain Lion	Wolf	Muskox
British Columbia	9 613	29 804	308	3 321		426	924		4 375	159	333[4]	
Alberta	18 000	12 000		18 000	1 000	255	26	0	5 050	33	0	
Saskatchewan	2 113	39 805	27	471	2 010				1 071	0	0	
Manitoba	4 510	35 450	185	680					1 570	0	450	
Ontario	10 700[4]	11 955[4]							4 500[4]		0	
Quebec	11 799[4]	3 849[4]	7 052[4]						1 432[4]		0	0
New Brunswick	1 287	27 165							801			
Nova Scotia	0	44 513							422			
Prince Edward Island												
Newfoundland	7 444		4 340						272		50[5]	
Yukon	1 080	0	1 222	0		239	5		215	0	45	0
Northwest Territories	691[4]		24 740[4]			221[4]	7[4]	60[4]	803[4]		0	207[4]

These data were obtained from a number of different agencies and are largely estimates. Because of methodological differences some caution should be used in interpreting the figures. The data in all cases include sport hunting kills. In many cases they also include kills by Native people. The figures for bear also include kills for the fur industry. For cougar and wolf, sport kills only are shown; additional cougar and wolves may have been killed for bounties and pelts.

Quebec and Yukon caribou kill data include both sports hunting and hunting by Native people. In Ontario and Alberta, only hunting by Native people is permitted, and these figures are not reported. In both Manitoba and Saskatchewan only the kill of woodland caribou is reported. The kill of barren-ground animals is not available.

[1]Mountain sheep include California bighorn, Dall's sheep, Rocky Mountain bighorn, and Stone's sheep.

[2]Bison hunting is permitted only in the Northwest Territories.

[3]Bear includes black, grizzly, and polar bear.

[4]1982 data.

[5]Labrador.

Source: Provincial/territorial agencies responsible for wildlife.

Beverly herd has been over-harvested in the past, while moose appears to be underutilized, at least regionally.

Taiga Plain

At the northern end of the Alberta plateau in the Slave River Delta, bison are hunted by both sport hunters and Native people. This combined pressure has depleted the stock outside Wood Buffalo National Park almost to extinction (fewer than 200 remaining). As mentioned earlier, the total bison stock within and outside the park once stood at 15 000 or more; it is now reduced to fewer than 5 000 animals.[19]

Northern Arctic

Hunting in this region has come under control; as a consequence, valued stocks are recovering. Polar bear, once hunted for food, are now hunted mainly for pelts. The hunt is rigidly controlled through a quota system. The annual reported kill of polar bear within Canada averages just under 700. This hunting pressure is considered relatively small, and Canada's polar bear population is not endangered. Muskox have been protected from hunting since 1971, and populations on many of the islands in the Northern Arctic ecozone have increased greatly over the past several decades.

Pollution

Oil transportation and offshore exploration and extraction pose a risk to waterfowl in coastal areas. Along the Pacific coast, migratory birds are exposed to oil slicks and spills from the tanker traffic between Alaska and the west coast of United States. In the Atlantic region, offshore oil exploration and development, particularly off Nova Scotia and Newfoundland, are expected to contribute to increased risk of oil spills. To date, oil pollution in Canada's Atlantic waters is due to shipping accidents. This is a relatively high-risk area because of heavy tanker traffic and inclement weather.

There have already been incidents where large numbers of seabirds were killed by oil spills. When the *Arrow* broke up in Chedabucto Bay (Nova Scotia) in the winter of 1970, a massive oil slick drifted southeastward to the vicinity of Sable Island, where it killed thousands of seabirds. Relatively few were lost at the site of the wreck.

Table 6.19
Successful Mammalian Introductions to Canada

Species	Introduction Where/When	Origin	Status	Intentional or Accidental
Opossum	Southeastern Ontario between 1850-1910, 1930-1935, and 1947-present (waves of migration); B.C. since 1925	U.S. (Washington State to B.C.)	extended distribution	natural migration
Nebraska Cottontail	First in Manitoba, 1914	U.S.	extended distribution	natural migration
Eastern Cottontail	B.C., by 1950	U.S. (Washington State)	extended distribution; established in the Sooke-Metchosin area	natural migration
European Hare	Southern Ontario 1909, 1912 and during the 1940s	Germany	well established in agricultural southern Ontario; unsuccessful in more northern areas of intentional introduction	accidental and intentional
Varying Hare	Newfoundland, 1864; Anticosti Island, Que., 1902-03	Europe	now established on both islands	intentional; harvested
Merriam (Minnesota) Gray Squirrel	Manitoba, 1930s	U.S.	extended distribution	natural migration
Eastern Fox Squirrel	Pelee Island, about 1890	Southern Ohio	now fairly established and common in areas of suitable habitat	intentional
Black Rat	Coastal B.C. (along with early settlement) after the Norway rat	Southern Asia	well established in B.C. settled areas, seaports, etc.	accidental
Alexandrian Rat	Vancouver and Queen Charlotte Islands and lower B.C. mainland, along with settlers from the Orient	Asia	well established in B.C.	accidental
Norway Rat	North America, around 1775	Europe	most settled areas	accidental
House Mouse	North America, with first Europeans	Europe	most settled areas	accidental
Nutria (Coypu)	Fraser River Delta, B.C.; Thunder Bay and Ottawa River areas of Ontario and Quebec since 1938	South America	imported for Canadian fur industry, established feral population; cold climate restricts their range	intentional; harvested; accidentally escaped from fur farms
Gray Fox	Southern Quebec, Ontario and Manitoba between 1930 and 1940	U.S.	rare; extended distribution; return to northern natural range (extirpated 300 years ago)	natural migration
Reindeer	Great Slave Lake area, NWT, 1911; Mackenzie River Delta, 1935	Norway	Mackenzie Delta herd remains strong	intentional; harvested
Fallow Deer	James Island, B.C., about 1895 (other releases on different islands, early 1900s)	Mediterranian Region and Asia	flourishing on James, Saltspring, Sydney Islands	intentional
Bison	Elk Island National Park, Alberta, 1907-1912 Thunder Hills area, Saskatchewan, transfer in 1969	Alberta and Alaska	herds released to parks remain strong Saskatchewan range spread since 1969 (southward and westward)	reintroduced to the prairies
Muskox	Yukon, early 1970s	Alaska	surviving, small herd	intentional and natural migration

Recent introductions include reindeer on the Belcher Islands in 1978 and bison in Jasper National Park and in the Lind area of the Northwest Territories.
Source: N. Novakowski, G. Moore and P. Reilly, *Exotic Mammals and Birds in Canada: A Historical Review* (Environment Canada, unpublished, 1975).

Off the Newfoundland coast, where thick-billed murres are found in large numbers during the summer, oil discharged from shipping and offshore drilling poses a risk. The common murre, nesting on islands along this coast, is likewise at risk. If exploration and offshore development of oil intensify, threats to seabirds may become more significant.

Disease

Disease can serve as one of the natural regulators of wildlife populations. Populations become stressed if habitat is reduced. When this happens, individuals become more vulnerable to disease. Epidemics often serve to bring populations back into balance. In some cases, diseases of domesticated species may spread into the wild population. For example, there was a bison anthrax outbreak in the Taiga Plain in 1962. Hybrid bison are still afflicted by brucellosis and tuberculosis, and culls have been undertaken in efforts to rid the bison population of these diseases.

Exotics

The intentional or accidental introduction of exotics often leads to unpredictable effects on the environment. In some cases, the displacement of native fauna by the invader has no significant consequences; in others, the effects can be disastrous. Tables 6.19 and 6.20 record successful introductions into various regions of Canada of non-native mammals and birds. (Fish introductions are discussed in Chapter 3.)

The Norway rat contributes to economic losses by pilfering stored grain, and the province of Alberta spends large sums of money to keep the rat population under control. The starling has become a Canada-wide pest in cities and in the countryside. It displaces other hole-nesting species such as the bluebird.

ASSESSMENT

An overall assessment of the state of Canadian wildlife must remain largely impressionistic. Data on population trends are available for some groups — particularly the more important commercial or sports species.* Population estimates are altogether lacking for a good many other fauna (reptiles, amphibians, insects), as well as for flora. Knowledge of habitat transformation and other parameters critical to understanding changing patterns in wildlife and their relationship to environmental forces is most often elementary or non-existent.

That Canada has and maintains a spectacular assemblage of big game species, fur-bearers and game birds is a remarkable feature that many other countries might envy. It signifies substantial commitment to protecting a natural heritage in the face of considerable economic pressures to clear the bush, pressures to which many other nations have succumbed. The Canadian situation reflects, in part, the territorial expanse of the country and the large uninhabited regions. However, a combination of good management and the effectiveness of a number of citizens' groups committed to conservation has a considerable influence on the current state of the wilderness. Major success stories include the rehabilitation of the endangered whooping crane, wood bison and peregrine falcon. Less spectacular but highly valued species have even been protected on occasion against natural sources of mortality. For example, deer in Ontario and elsewhere are given supplementary feeding during unusually severe winters.

An examination of Tables 6.3 to 6.5 indicates that most important species are now holding stable or increasing their populations. There are a few exceptions. Some herds of woodland caribou in Alberta, Saskatchewan, Quebec and southern Labrador are decreasing. Other populations that are now stable are still at relatively low levels compared with former times (e.g., bison, antelope, Rocky Mountain and California bighorn sheep).

A national overview cannot describe all regional changes in species richness or the abundance of particular populations. A number of bird breeding grounds have suffered reduced productivity owing to changes in water regimes associated with construction and operation of large dams. While big game and fur-bearing populations have remained strong throughout most areas of Canada, they have been displaced from some regions. For example, prairie populations of these fauna have been greatly depleted, but most species that once thrived there have found refuge elsewhere (with the exception of the great plains grizzly).

There has been considerable discussion about the fragility of northern ecosystems. Several important species have in the past suffered drastic population reductions (muskox, some herds of caribou, polar bear). The main reasons for this have been overharvesting and climatic conditions.

Concerns today are focused on threats to wildlife populations from oil spills and development activities associated with oil and gas exploration and transportation.

In all parts of Canada, wildlife habitat has been altered by the construction of dams, roads and pipelines, as well as by the conversion of forests and the draining of wetlands for agriculture and housing. In some regions, such as the Boreal Plain, vast areas of natural habitat have been lost. For example, where enormous amounts of land have been drained for agricultural use in the prairies, mallard populations are declining. In eastern Canada, the black duck shows similar declines as a result of habitat loss.

Land conversions have had positive effects on

*However, this is not to suggest that there are not difficulties in obtaining reliable data — e.g., on cover-seeking groups — particularly in the Boreal regions.

Table 6.20
Successful Bird Introductions to Canada

Species	Introduction Where/When	Origin	Current Status	Intentional or Accidental
Cattle Egret	Newfoundland, first sighted 1952 Nova Scotia, 1957 New Brunswick, 1961 Quebec, 1960 Ontario, 1956 Manitoba, 1961 NWT, sighted in 1971	Africa	now well established across Canada	natural migration
Ring-necked Pheasant	Newfoundland, 1950s (escaped from commercial poultry establishment); New Brunswick, P.E.I., Ontario, around 1900; B.C., between 1882 and 1960	Ukraine	area of St. John's, appears established, other maritime introductions surviving; Ontario, successfully established; B.C., successful in southern parts of mainland, Queen Charlotte and Vancouver Islands (small populations)	accidental; intentional; harvested
California Quail	Near Victoria, B.C., 1860 and 1870s; Vancouver Island and mainland B.C., 1890s; other areas of B.C., early 1900s	U.S.	well established but populations are relatively low; (lower mainland and Queen Charlotte Islands unsuccessful)	intentional; natural migration
Mountain Quail	Vancouver Island, 1870-1880s	U.S.	established, but in small populations in areas on Vancouver Island and restricted range inland	intentional
Gray Partridge	P.E.I., 1930; Nova Scotia, 1926; New Brunswick, 1926; southwestern Quebec and Ontario, late 1930s; Manitoba, Saskatchewan, Alberta, 1908; southern interior of B.C., 1904	Europe (Czechoslovakia/ Hungary)	almost always a successful introduction, except in New Brunswick; B.C. has small population	intentional; harvested as game
Chukar Partridge	P.E.I., Saint John, N.B., Southern B.C., 1950-1955; Southern Saskatchewan, 1938; Manitoba, 1938	U.S.	B.C. relatively strong population	intentional
Ruck Dove	Canada, around 1906	Europe	range spread across southern Canada, mainly around human settlement	intentional
English Skylark	Near Victoria, B.C., 1903 and 1913	Eurasia and North Africa	well established	intentional
Common Starling	North America, 1980	Europe	established its range across Canada by 1950	accidental
Crested Mynah	Vancouver, around 1897	Orient	established mainly in the Vancouver area	accidental
English Sparrow	North America, 1850; first Canadian releases at Quebec and Halifax	England	established its range across Canada by 1890	intentional
House Finch	southern Ontario, since 1930	New York City	well established	natural migration

Source: N.S. Novakowski, G. Moore and P. Reilly, *Exotic Mammals and Birds in Canada: A Historical Review* (Environment Canada, unpublished, 1975). E. Godfrey, *The Birds of Canada* (National Museums of Canada, 1979).

some wildlife species. For example, agricultural habitat favours species such as meadowlarks (requiring fields), bobolinks (needing short grass), and doubtless also woodchuck; mixtures of forest and open areas favour foxes, woodcocks, coyotes and deer. A good deal more research is required for a full understanding of the important linkages between human activities and the maintenance of wildlife.

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Land Use Changes

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INTRODUCTION

Land use change takes place all the time as a result of virtually every form of human activity, whether it be urban sprawl, industrial development, exploration and exploitation of non-renewable resources, management of renewable resources, development of transportation networks, or the setting aside of lands for recreational or conservation purposes. Land use change can also come about through natural circumstances such as floods, droughts, fire and the spread of disease.

Whatever the cause, land use changes can produce significant environmental effects. For example, clearcutting a forested area can lead to soil erosion, with increased sediment flow to nearby waters and consequent changes in aquatic life. The construction of major dams can flood large areas, dramatically changing the habitat of indigenous animal species; this may be only a temporary dislocation, but it could endanger the species if other acceptable habitat is not available. In some cases, land use changes may result, intentionally or unintentionally, in an improved habitat for some species, and such changes are sometimes regarded as success stories.

Views of the importance of such changes vary widely. For example, the sports fisherman and the forester can be expected to respond differently to the stream sediment problem; the industrial developer and the wildlife conservationist will react differently to proposals to construct major dams. The changing relative importance of one set of views compared with another over time is a function of many factors — the amount of leisure time available, the state of the economy, and the degree of understanding about ecosystem relationships, for example. There seems to be little doubt, however, that land use change decisions involve trade-offs between the importance of the 'before' and 'after' uses and conditions.

From an ecological point of view, there may be strong scientific reasons to preserve certain land areas in their natural state because of their unique features. There may be other areas that, while not necessarily unique in a one-of-a-kind global sense, are considered representative of the biogeography of the country and should be preserved for historical and cultural reasons. Aside from such considerations, there are no clear trade-off guidelines that will stand up indefinitely in all circumstances.

During the last 10 years, however, procedures have been developed and are continuing to evolve that are designed to improve this situation. These involve the requirement to conduct environmental impact assessments for major new economic development projects before approval is given to proceed with construction. These procedures usually require the provision of baseline information about the ecology of the area, an assessment of the potential environmental impact, and the development of techniques to minimize adverse effects. Such procedures vary from jurisdiction to jurisdiction and often involve public hearings. Some projects have been cancelled, redesigned or relocated as a result of the review process.

Land should be considered one of the resources for sustainable development in a world setting, and its use in Canada should be monitored like that of other resources. Is prime agricultural land being lost at such a rate or to such an extent that Canada will be significantly more dependent upon food imports in the foreseeable future? What is the outlook for world food production? Will agricultural or forestry production become so depleted that export earnings will decrease dramatically and force other serious economic and social hardships on Canadians? Land use change is, of course, only one factor that would have to be considered in examining such questions.

This chapter provides data on a variety of activities that lead to land use change. Attention is focused on various aspects of industrialization — disturbances caused by mining and by the construction of various transportation corridors and dams — and on an examination of a particular study to assess built-on lands and their trends over time. Data concerning fire and disease in forest ecosystems, changes in cropping practices, conversion of agricultural and rural lands to urban uses and the loss of wetlands have already been presented (see Chapters 3 and 4). This chapter also presents information and time trends concerning lands set aside for parks, wildlife protection and ecological reserves.

Data have been drawn from various sources, both federal and provincial. Much of the information is presented in terms of individual provinces, provincial groupings, or for Canada as a whole, because it could not readily be aggregated by ecozone. Data on dams, parks, wildlife areas, and ecological reserves were, however, available in a form that permitted some aggregation by ecozone for different periods of time. In some cases, such as land use for mining, one set of data represents the recent situation; comparable data for earlier periods were not available for trend analysis. Where possible, however, the period covered is the past 25 to 35 years, although data on the construction of dams cover the period from 1921 on.

LAND AREA DISTURBED, UTILIZED AND ALIENATED BY MINING*

Data on land use by mining have not been collected systematically. Despite this, and setting aside questions of definition (for example, should abandoned and overgrown mines be included?), it is possible to make estimates of land disturbed, utilized and alienated by

*Disturbed, utilized and alienated refer to three levels of impact: the first is lands actually mined or used for waste heaps or tailings; the second is lands used for buildings, roads and other facilities required for mining activities; and the third is lands under direct ownership or leased by mining companies.

Table 7.1
Land Area Disturbed, Utilized and Alienated by Mining[1]
(hectares)

Province/ Territory	Metalic & Non-metallic	Uranium	Asbestos	Potash	Coal	Oil Sands	Construction Materials[2]	Total
Newfoundland	4 880		297				2 750	7 927
Prince Edward Island							575	575
Nova Scotia	1 150				495		4 025	5 670
New Brunswick	1 450				6 100		3 450	11 000
Quebec	21 885		3 525				31 050	56 460
Ontario	48 420	1 174	173				46 000	95 767
Manitoba	1 986						10 350	12 336
Saskatchewan	411	279		4 110	6 660		12 650	24 110
Alberta					8 260	4 850	10 500	23 630
British Columbia	18 115	NA	NA		6 175		16 675	40 965
Yukon & Northwest Territories	5 650		237		NA		NA	5 887
Total	103 947	1 453	4 232	4 110	27 710	4 850	138 025	284 327
% attributed to Mine Wastes[3]	80	73	73	73	75	58	87	82

NA: not available and not significant overall.
[1]Includes land area disturbed by mine wastes and facilities and those lands alienated from alternative uses due to their proximity to, or encirclement by, mine wastes or fixed facilities (e.g., buffer zones).
[2]Construction materials include sand, gravel and crushed stone.
[3]Mine wastes include all lands affected by open pits, strip mines, underground shaft sites, tailings, waste rock, overburden dumps, slag and settling ponds.
Source: Environment Canada, *Mining, Land Use and the Environment. A Canadian Overview*, Land Use in Canada Series No. 22 (Ottawa: 1982).

mining. These are summarized in Table 7.1 and include areas disturbed by mine wastes and facilities, as well as those lands that have alternative uses (e.g., buffer zones). The data are typical of the early 1980s and, given current economic conditions, have probably not changed much since then.

Mining for metals, non-metals and construction materials (sand, gravel and crushed stone) accounts for about 85 per cent of the total area involved. For each mining category, the contribution of wastes to the total area disturbed ranges from 58 per cent for oil sands to 87 per cent for construction materials. Wastes from two categories, metallic and non-metallic mines and construction materials, account for 82 per cent of the total area of land disturbed, utilized or alienated by mining.

The total area involved is very small compared with the total land area of the country — about 0.03 per cent. Furthermore, some mining activities take place in remote areas and therefore do not compete with alternative economic uses. However, some operations take place at the expense of productive agricultural lands or forestlands or wildlife habitat.* Such activities also require roads, power transmission lines and settlements, which may also impinge on agricultural lands or forestlands. The single most important environmental hazard posed by mining operations is the effect of wastes — especially the contamination of surface and underground water systems. Contamination data are presented in Chapter 8.

*Remote mining operations and oil exploration have significant environmental effects on the often fragile ecologies of the virgin wilderness or the lifestyles of remote settlements, usually of Native people. This issue came to the forefront in the Berger Commission inquiry into the Mackenzie Valley Pipeline proposal.

TRANSPORTATION CORRIDORS

Dedicating large tracts of land (rights-of-way) as transportation corridors is an integral part of the development of modern transportation systems, and their expansion parallels the indicators of long-term economic growth. Much has been written about the importance of the transcontinental railway in Canada's history. A vast network of paved roads has been built to meet the need for road transport and passenger cars. Electrical transmission lines have been constructed to link the demand for power with the remote supply (i.e., hydro-electric projects). Increasing energy requirements and the desire for self-sufficiency have led to the construction of major oil and natural gas pipelines. These developments represent significant land use changes, although some may not cause permanent disturbances — buried pipelines, for example, do not necessarily preclude subsequent productive use of the land.

Data on the length of various transmission corridors (railroads, paved roads, electrical transmission lines, oil pipelines and gas pipelines) are summarized in Table 7.2. The data on oil and gas pipelines relate to trunk and transmission lines respectively (i.e., those

Table 7.2
Length of Various Transportation Corridors, 1960-1983
(kilometres)

	Yukon & Northwest Territories	British Columbia	Prairie Provinces	Ontario	Quebec	Atlantic Provinces	Canada
Railroads[1]							
1960	93	7 058	31 311	16 487	8 413	6 949	70 856
1965	93	6 973	30 546	16 013	8 430	6 854	69 758
1970	302	7 033	31 471	16 154	8 576	6 701	70 782
1975	302	7 703	30 981	15 789	8 689	6 614	70 714
1980	302	7 344	28 440	15 502	8 322	6 521	67 067
1981	209	7 292	28 085	15 367	8 322	6 462	66 372
Percentage Change 1960-1981	+125	+3	−10	−7	−1	−7	−7
Paved Roads[2]							
1960	27	13 434	18 731	37 569	29 156	14 474	113 391
1965	31	17 603	29 199	62 776	34 943	15 890	160 442
1970	71	21 407	39 265	54 993	41 732	25 107	182 575
1975	228	29 008	56 988	66 921	55 371	31 857	240 375
Percentage Change 1960-1975	+744	+116	+204	+78	+90	+120	+112
Electrical Transmission[3]							
1960	220	6 983	41 139	29 023	18 212	6 663	102 241
1965	574	8 845	50 487	31 960	18 397	9 852	120 115
1970	1 142	13 776	57 280	37 013	21 163	14 553	144 929
1975	1 696	15 072	65 088	39 847	26 436	14 361	162 500
1980	1 724	17 741	71 163	41 655	29 987	16 882	179 150
1982	1 723	18 794	74 369	40 418	31 785	17 182	184 271
Percentage Change 1960-1982	+683	+169	+81	+39	+75	+158	+80
Oil Pipelines[4]							
1960		842	5 851	268	236		7 197
1965		2 031	7 815	375	341		10 562
1970		1 755	11 481	510	342		14 088
1975		1 755	12 438	711	342		15 246
1980		1 749	13 886	1 475	452		17 561
1983		1 647	13 884	1 475	451		17 456
Percentage Change 1960-1983		+96	+137	+450	+91		+143
Gas Pipelines[4]							
1960		1 790	9 652	5 738	40	22	17 241
1965		2 496	14 846	5 454	40	22	22 858
1970		3 888	21 066	5 812	238	22	31 025
1975		5 042	27 249	9 223	238	22	41 774
1980		5 231	31 561	9 441	256	22	46 564
1982		5 468	34 219	10 212	289	22	50 210
Percentage Change 1960-1982		+205	+255	+78	+622	0	+191

[1]Railroads are mainline railroads. Canada total includes a small length in the U.S., operated as part of the Canadian systems.

[2]Paved roads are federal, provincial and municipal roads and streets.

[3]Electrical transmission lines include all transmission circuits >20 000 volts.

[4]Oil and gas pipelines are trunk and transmission lines respectively.

Source: Railroads: Statistics Canada, Annual Catalogue 52-209.
Paved Roads: Statistics Canada, Annual Catalogue 53-201.
Electrical Transmission Circuits: Statistics Canada, Annual Catalogue 57-202.
Oil Pipeline Transport: Statistics Canada, Annual Catalogue 55-201.
Gas Pipeline Transport: Statistics Canada, Annual Catalogue 57-205.

carrying unrefined oil or natural gas from the production field to the refinery or distribution centre). Generally, there has been a substantial growth in all categories except railroads, where the abandonment of some lines has led to an overall decrease since 1960. Even here, however, there has been growth in the Territories and in British Columbia. There have also been regional differences in the percentage change for other categories. For example, there was marked growth in the length of electrical transmission circuits in the Territories during the 1960s and early 1970s but little change since then.

There was substantial growth in paved roads for all regions between 1960 and 1975. Paved roads data for 1980 were not compiled in the same way and therefore cannot be used for trend analysis. The percentage growth in paved roads was largest in the Territories and least in Ontario and Quebec, where an established paved road network already existed in 1960. In terms of the actual length of paved roads added between 1960 and 1975, the prairie provinces led the way with over 37 000 kilometres, followed by Ontario with almost 30 000 and Quebec with over 25 000 kilometres.

For electrical transmission lines, the Territories, British Columbia and the Atlantic provinces had a greater-than-average change since 1960. The well developed industrial base in Ontario explains the lower growth in new electrical transmission circuits in this province.* On the other hand, Ontario showed the greatest percentage change in oil pipeline length, although the actual length of oil pipelines is far greater in the prairie provinces. For gas pipelines, the greatest percentage change was in Quebec, with the actual length again being far greater on the prairies. The oil to gas conversion programs of the federal government will lead to significant increases in gas pipeline construction, and this trend will undoubtedly be reflected when more recent data become available.

A more detailed analysis of electrical transmission lines and oil and natural gas pipelines is presented in Table 7.3. As the kilovoltage of the electrical transmission circuits increases, so does the size of the corridor (height of the pylons and width of the right-of-way). A breakdown of the data into a number of kilovoltage ranges, and a comparison between 1960 and the most recent figures, show the marked increase in the higher kilovoltage circuits.

For oil and natural gas, the data given in Table 7.2 relate only to the main trunk/transmission pipelines. These figures exclude gathering pipelines, largely confined to oil/gas field operations areas, and product lines, which carry refined products such as gasoline and fuel oil. Distribution pipelines for the delivery of gas to homes and industry are now approaching 100 000 kilometres, but are confined largely to urban areas.

CONSTRUCTION OF DAMS

The construction of dams has been an integral part of Canada's development as an industrialized nation. The resulting reservoirs have flooded valleys and obliterated many wild rivers. They have, on occasion, had catastrophic effects on local terrestrial and aquatic ecosystems. A notable example is the elimination of traditional salmon runs. The effects of the Bennett Dam on ecosystems in the Peace-Athabasca Delta have already been discussed (see Chapters 5 and 6). Nature ultimately adapts to these restructured water systems, and new ecological balances emerge.

Data on the construction and characteristics of dams in Canada have been maintained for many years. They cover such factors as the area of the reservoir, the depth of water or height of the dam, and the volume of water in the reservoir. For this discussion, storage capacity (volume) has been selected as one general indication of the potential for causing ecological change. Actual change will vary from site to site depending on many factors such as topography, vegetative cover, water flow, seasonal climate variability, and biotic characteristics of the area before the dam was constructed. Storage capacity does not necessarily reflect the actual volume of water stored at any particular time because this depends on both climate conditions and operational factors.

Table 7.4 provides the number and aggregated storage capacity of dams by ecozone as of 1921 and for each decade thereafter. For example, in the Pacific Maritime ecozone, the number of registered dams grew from 17 in 1921 to 48 in 1981, and the aggregated storage capacity increased from 2 994 million cubic metres to 29 607 million cubic metres. During this time the total number of dams in Canada increased by a factor of 15, and total storage capacity grew by a factor of more than 50.

Until 1941 there was steady but unspectacular growth in all regions. In the decades that followed, growth was more unevenly distributed to meet developing economic needs in various parts of the country. Until the end of the 1960s, the fast-flowing rivers of the Boreal Shield provided most of the hydro-electric power for the industrial heartland of the Mixed-Wood Plain. Since then, there has been tremendous development in the more remote Taiga Shield ecozone of hydro-electric projects like Churchill Falls (Labrador), James Bay (Quebec), and Churchill-Nelson (Manitoba). The storage capacity of reservoirs in this ecozone increased from 34 189 million cubic metres to 246 194 million cubic metres between 1971 and 1981. This was due largely to the construction of the monumental James Bay development project. The

* This may, however, be deceptive. The upgrading of transmission capacity, using existing corridors, is a factor that should be considered because, like the improvement of highways, it requires the widening of existing rights-of-way. Although no data are available on additional land requirements, it is highly likely that, in the urbanized/industrial areas of the Mixed-Wood Plain, the area devoted to transmission lines is far greater than it would appear from a simple accounting of linear kilometres.

Table 7.3
Corridor Lengths for Electrical Transmission Circuits, Oil Pipelines and Natural Gas Pipelines
(kilometres)

	Yukon & Northwest Territories		British Columbia		Prairie Provinces		Ontario		Quebec		Atlantic Provinces		Canada	
	Latest[1] Year	% Change from 1960	Latest Year	% Change from 1960	Latest Year	% Change from 1960	Latest Year	% Change from 1960	Latest Year	% Change from 1960	Latest Year	% Change from 1960	Latest Year	% Change from 1960
Electrical Transmission														
20-99 kV	723	+1 105	5 377	+15	45 992	+35	12 721	+10	3 901	−53	7 437	+31	76 151	+18
100-299 kV	1 000	+521	8 493	+332	26 265	+275	25 473	+46	13 071	+99	8 469	+782	82 771	+142
300-599 kV			4 924	+1 406	2 112		2 224		6 590	+335	673		16 523	+579
600 kV									8 223		603		8 826	
Total	1 723	+680	18 794	+169	74 369	+171	40 418	+36	31 785	+75	17 182	+158	184 271	+80
Oil Pipelines														
Trunk			1 646	+95	13 884	+137	1 475	+450	451	+91			17 456	+143
Gathering			718	+465	13 090	+202	73						13 881	+211
Product	89	−66	56		2 531	+1 533	2 095	+55	250	+198			5 020	+163
Total	89	−66	2 420	+136	29 505	+185	3 643	+124	701	+119			36 357	+168
Gas Pipelines														
Transmission			5 468	+205	34 219	+255	10 212	+78	209	+512	22	0	50 210	+191
Gathering	55		3 184	+382	21 596	+470	2 130	+46			21	+110	26 986	+356
Distribution			11 847	+143	42 228	+457	34 221	+123	3 502	+95	146	+181	91 943	+210
Total	55		20 499	+180	98 043	+386	46 563	+107	3 791	+107	189	+128	169 139	+220

[1]Latest year: Electrical Transmission Lines: 1982; Oil Pipelines: 1983; Gas Pipelines: 1982.
Source: Electrical Transmission Circuits: Statistics Canada, Annual Catalogue 57-202.
Oil Pipeline Transport: Statistics Canada, Annual Catalogue 55-201.
Gas Pipeline Transport: Statistics Canada, Annual Catalogue 57-205.

Table 7.4
Number and Storage Capacity of Registered Dams in Canada, 1921-1981

	2 Boreal Cordillera		3 Pacific Maritime		4 Montane Cordillera		5 Boreal Plain		6 Taiga Plain		7 Prairie		8 Taiga Shield		9 Boreal Shield		10 Hudson Bay Plain		11 Mixed-Wood Plain		12 Atlantic Maritime		Canada	
	a	b	a	b	a	b	a	b	a	b	a	b	a	b	a	b	a	b	a	b	a	b	a	b
1921			17	2 994	7	14									11	10 756			5	452	1	109	41	14 325
1931			23	3 310	17	332	4	180			2	1			46	23 625			13	475	15	1 162	120	29 085
1941			24	3 865	23	1 348	4	180			6	51			55	27 260			15	480	19	1 315	146	34 499
1951			27	4 196	34	2 385	6	302			16	610	1	271	73	68 518			24	2 401	22	1 250	203	79 933
1961	2	3	40	29 453	42	36 546	7	524			44	2 522	4	592	125	99 430			35	33 326	37	1 905	336	204 301
1971	2	3	45	29 592	49	117 406	12	11 376			66	24 763	41	34 189	162	256 597			46	33 672	43	2 880	466	510 478
1981	2	3	48	29 607	55	147 592	14	13 144			66	24 763	124	246 594	169	267 260			48	33 672	50	3 077	576	765 712

a: cumulative number.
b: storage capacity (millions of cubic metres).
Totals may not add due to rounding.
Source: Department of Energy, Mines and Resources, *Registered Dams in Canada* (Ottawa: 1983).

average storage capacity of reservoirs (a rough indication of dam size) remained relatively stable between 1921 and 1941 — about 275 million cubic metres. By 1981, the average storage capacity had reached 1.3 billion cubic metres.

BUILT-ON LANDS

One of the most drastic alterations that human beings can make to land is to build on it. Any Canadian city has landscapes ranging from the ecologically lifeless (the concrete canyons of the core), to straggling plant life in inner city backyards, to densely wooded suburban lots. Built-on lands are often associated with garden hybrids and imported plants, a potential source for the introduction of exotic plant life. It should also be noted that a residential neighbourhood well wooded with mature trees could have the same biomass as a forest. Moreover, any rural landscape has roadside rights-of-way that are significant habitats for wildflowers or escaped garden plants (witness the spectacular displays of lupins in the Atlantic Maritime ecozone).

Built-on land may be defined as land occupied by residential, commercial or industrial buildings, roadways (rural and urban), transport terminals, airports, rail beds, and many other types of installation. There is no systematic compilation of built-on lands for the whole of Canada, although most municipalities and regional governments produce land use maps. One nation-wide study on this aspect of land use is reported in Tables 7.5 to 7.7. The figures in these tables include farmyards and urban parks, but not rights-of-way, transmission lines or buried pipelines, presumably because such land could be used for other purposes.

The estimated distribution of built-on lands for the years 1951, 1961, 1971 and 1981 is shown in Table 7.5. There has been rapid growth in the area classed as urban and rural settlement, less rapid growth in rural transportation, and a decline in farmyard area. These trends are to be expected, given the changes in the total population and rural-farm population and given the degree of urban-oriented economic development that occurred during this period.

A national and province-by-province breakdown of the total built-on area and the changes during each decade between 1951 and 1981 are presented in Table 7.6. Changes in the growth of built-on land are clearly evident, particularly in the decade 1971-1981, when some provinces, such as Ontario, Manitoba and Saskatchewan, show a marked slowing down and others, such as Newfoundland, New Brunswick and Alberta, show a marked increase.

Interprovincial differences in the percentage distribution between the three built-on land categories, as well as comparisons between the total built-on land area and the total land area for each province, are presented in Table 7.7, based on the 1981 estimates. Overall, the total built-on area represents a small fraction (0.6 per cent) of the total land area. This percentage varies from a low of 0.01 per cent in the Territories to a high of 6 per cent in Prince Edward Island.

Table 7.5
Estimated Distribution of the Area of Built-on Lands
(thousands of hectares)

Canada	1951	1961	1971	1981
Urban & Rural Settlements	943.7	1 477.0	1 902.7	2 600.1
Rural Transportation	1 651.4	1 969.3	2 439.3	2 715.6
Farmyards	775.2	656.4	536.6	462.2
Total Built-on	3 370.3	4 102.7	4 878.6	5 777.9

Source: J.A.G. Hansen, "Built-on Lands: Definition and Canadian Area Estimates", *Plan Canada* 17/4 (1984): 122-133.

There are also marked provincial differences in the distribution between urban and rural settlements, rural transportation and farmyards. Built-on areas classed as urban and rural settlements range from a low of 10 per cent of total built-on area in Saskatchewan to a high of 73 per cent in New Brunswick. Those classed as rural transportation range from a low of 25 per cent of built-on area in New Brunswick to a high of 79 per cent in Prince Edward Island. For farmsteads, the low is 0.5 per cent, in Newfoundland, and the high is 17 per cent, in Saskatchewan.

SPECIAL RECREATION AND CONSERVATION AREAS

Modern urbanization has led to increasing demands for recreational land. This is a particularly urgent problem for large urban centres. Recreational areas like Muskoka, the Laurentians and the Gulf Islands need careful environmental planning if they are not to become a clutter of cottages, motels and souvenir shops. Recreational high tech, such as snowmobiles and dirt bikes, usually conflicts with more nature-oriented activities such as hiking, birdwatching, canoeing and the like. As an example, the development of a ski resort involves deforestation of mountain slopes, construction of hotels, road-building, and so forth. Beaches are also vulnerable; Wasaga Beach on Georgian Bay is an example. Private owners of recreational land may deny public access to waterfronts. Almost any lake close to a major urban area is virtually inaccessible. Governments responded in part to this public need for recreational space by establishing a system of parks.

The first national park in Canada (Banff) was already established in 1885. The main purpose of national parks has been clearly stated to be, first, to protect the national heritage for future generations

Table 7.6
Estimated Total Built-on Land Areas and Changes, 1951-1981
(thousands of hectares)

Province/ Territory	1951 Total Built-on Area	Additional Built-on Area			1961 Total Built-on Area	Percentage Increase 1951-1961
		1951-1961	1961-1971	1971-1981		
Territories	11.4	5.4	8.1	4.9	29.8	161.4
British Columbia	268.5	72.8	99.7	80.4	521.4	94.5
Alberta	578.4	232.6	197.2	410.2	1 418.4	145.2
Saskatchewan	658.6	35.4	31.5	18.9	744.4	13.0
Manitoba	243.5	65.6	68.4	20.3	397.8	63.4
Ontario	761.6	156.7	170.7	94.3	1 183.3	55.3
Quebec	414.4	96.8	135.6	148.6	795.4	91.9
New Brunswick	208.7	38.3	30.1	73.5	350.6	68.0
Nova Scotia	123.8	12.3	17.2	21.6	174.9	41.3
Prince Edward Island	28.6	1.7	2.0	1.6	33.9	18.5
Newfoundland	72.8	14.8	15.4	25.0	128.0	75.8
Total	3 370.3	732.4	775.9	899.3	5 777.9	71.4

Source: J.A.G. Hansen, "Built-on Lands: Definition and Canadian Area Estimates", *Plan Canada* 23/4 (1984): 122-133.

Table 7.7
Comparison Between Built-on and Total Land Areas and Percentage Distribution of Built-on Land Area, 1981

Province/ Territory	Total Land Area[1] (millions of hectares)	1981 Built-on Area (thousands of hectares)	Built-on as % of Total	% Distribution of Built-on Area		
				Urban & Rural Settlement	Rural Transportation	Farmstead
Territories	377.8	29.8	0.01	25	74	1
British Columbia	93.0	521.4	0.6	53	42	5
Alberta	64.4	1 418.4	2.2	52	41	7
Saskatchewan	57.0	744.4	1.3	10	73	17
Manitoba	54.8	397.8	0.7	29	57	14
Ontario	89.1	1 183.3	1.3	45	45	10
Quebec	135.6	795.4	0.6	52	42	6
New Brunswick	7.2	350.6	4.9	73	25	2
Nova Scotia	5.3	174.9	3.3	42.5	55	2.5
Prince Edward Island	0.6	33.9	6.0	13	79	8
Newfoundland	37.0	128.0	0.3	61.5	38	0.5
Total	922.0	5 777.9	0.6	44	47	9

[1]Excludes inland water.
Source: J.A.G. Hansen, "Built-on Lands: Definition and Canadian Area Estimates", *Plan Canada* 23/4 (1984): 122-133.

and, second, to provide benefit, education and enjoyment for Canadians.

Information provided by provincial and federal agencies shows the number and size of various categories of parks across Canada. Three categories of parks have been used: wilderness area (greater than 16 000 hectares), unique natural areas, and natural environment recreation areas (greater than 200 hectares). The data have been grouped by ecozone and summarized to reflect the situation at five-year intervals beginning in 1961 (Table 7.8). The most recent data, usually 1983, were also included. For each category, there are some ecozones with no entries. For example, there are no designated wilderness areas in the Prairie, Taiga Shield or Northern Arctic ecozones. Other ecozones have many designated wilderness areas: there are 13 in the Pacific Maritime, 12 in the Montane Cordillera, and 16 in the Boreal Shield. Overall, the number and the total area designated as wilderness areas have about doubled in the period since 1961.

The number and size of unique natural areas has roughly tripled since 1961. For natural environment recreation areas the actual number has increased by a factor of more than three, but total area has increased by less than 50 per cent since 1961. The total land area involved for all three categories in 1981 amounted to 33 million hectares. This can be compared with the estimated built-on land area of 5.7 million hectares, or with the total land area (excluding inland waters) of 922 million hectares.

In compiling its annual report, the Federal-Provincial Parks Conference also differentiates three types of protected areas within each class or category. Type 1 areas are completely protected and dedicated to outdoor recreation and nature study only. Type 2 areas are primarily for outdoor recreation and lands reserved from sale, but some resource exploitation may be allowed. Type 3 areas are set aside for multiple resource use, including recreation, but they are also reserved from sale. Information at this level of detail was not available in a form that could be shown by ecozone. However the information was available by jurisdiction. These data were assembled through a completely different process from that used to prepare Table 7.8, and some of the totals are quite different. They appear to be internally consistent, however, and can be used to illustrate the extent to which park areas are protected.

The numbers and areas involved for all three types together and for Type 1 (fully protected) are summarized in Table 7.9. Type 1 is also shown as a percentage of the total. In British Columbia, some 4.8 million hectares have been designated as wilderness areas, of which 72 per cent, or 3.5 million hectares, is identified as fully protected. In Alberta, however, with some 5.9 million hectares of wilderness area, only 32 per cent, or 1.9 million hectares, is fully protected. In Quebec only 1.6 per cent of the wilderness area is identified as fully protected. For the natural environment recreation areas, the percentages range all the way from 0 to 100 per cent, with the overall national figure being 11 per cent.

Some areas have been set aside or reserved for specific purposes such as wildlife areas or refuges, bird sanctuaries and biosphere/ecological reserves. Table 7.10 provides a summary of the number and size of such areas by ecozone at five-year intervals since 1961. Some of these areas may be part of one or other of the parks classes given in Table 7.8, so that it is not appropriate to sum the figures in the two tables. The overall number and the size of designated wildlife areas/refuges have grown dramatically, from only one in 1961 (2 500 hectares) to 140 (3 million hectares) in the latest entry. The growth in numbers has occurred mainly in the Boreal Plain, Prairie and Atlantic Maritime regions, but the bulk of the increase in size is attributed to a single wildlife area in the Hudson Bay Plain. There are seven ecozones that have no designated wildlife areas.

There was a considerable number of bird sanctuaries already established in 1961 and, overall, there has been about a 50-per cent increase since then. The increase in area has been about 10 per cent. There are only three ecozones (Tundra Cordillera, Boreal Cordillera and Taiga Plain) that have no bird sanctuaries.

Some years ago, as part of the International Biological Program, Canadian scientists identified a lengthy list of Canadian sites that should be set aside and protected for ecological reasons. This program was followed by another UNESCO international program called Man and the Biosphere, part of which was the development of an international register of designated biosphere reserves. Efforts have been made in Canada to co-ordinate the scientific interests and concerns relating to these two international programs, but the legislative action required to implement their recommendations has developed only slowly across the country. Available information relating to lands actually designated as biosphere/ecological reserves is summarized in Table 7.10. Before 1966, no lands were so designated, but the overall number grew from 34 in 1971 to more than 400 in 1983. These figures may be somewhat misleading, because the dates of establishment for the reserves under Alberta's jurisdiction were not available; the information for that province was therefore assigned to the last entry. The total area involved is much smaller than for either of the other categories (wildlife areas, bird sanctuaries). Only two biosphere reserves have been nominated by Canada for inclusion in the international registry.

INTERNATIONAL CONVENTIONS

Canada is a signatory to two international conventions related to protected areas: the Convention Concerning the Protection of the World Cultural and Natural Heritage, which came into force in 1976 (the same year that Canada became a participant), and the Conven-

Table 7.8
Federal and Provincial Parks by Category and by Ecozone, 1961-1983

Park Category[1]	To Year[2]	1 Tundra Cordillera		2 Boreal Cordillera		3 Pacific Maritime		4 Montane Cordillera		5 Boreal Plain		6 Taiga Plain		7 Prairie		8 Taiga Shield	
		a	b	a	b	a	b	a	b	a	b	a	b	a	b	a	b
Wilderness Areas (>16 000 ha) Class A	1961			2	114	10	2 736	7	1 900	2	685	1	4 481				
	1966			2	114	10	2 736	7	1 900	2	685	1	4 481				
	1971			2	114	11	2 807	8	1 929	2	685	1	4 481				
	1976	1	477	9	3 667	13	2 922	10	1 982	2	685	1	4 481				
	1981	1	477	9	3 667	13	2 926	11	2 014	2	685	1	4 481				
	1983	1	477	9	3 667	13	2 926	12	2 063	2	685	1	4 481				
Unique Natural Areas or Monuments Class C	1961					1	0.1			1	0.7			4	0.04		
	1966					1	0.1			1	0.7			5	1.0		
	1971					1	0.1	1	1.2	2	1.7			7	18.2		
	1976					1	0.1	1	1.2	3	2.5			10	33.3		
	1981					1	0.1	2	2.2	3	2.5			10	33.3		
	1983					1	0.1	2	2.2	3	2.5			10	33.3		
Natural Environment Recreation Areas (>200 ha) Class D	1961					5	5.7	8	6.3	18	315			15	75.6		
	1966			1	4.6	6	9.4	14	15.8	21	452			23	110		
	1971			1	4.6	11	52.6	18	24.9	29	612			28	116		
	1976			1	4.6	16	64.8	28	61.2	35	624	1	0.4	33	127	3	3.8
	1981			1	4.6	19	73.7	32	115	38	637	1	0.4	34	128	3	3.8
	1983			1	4.6	19	74.4	35	118	39	639	2	1.8	34	128	5	17.4

Park Category[1]	To Year[2]	9 Boreal Shield		10 Hudson Bay Plain		11 Mixed-Wood Plain		12 Atlantic Maritime		13 Southern Arctic		14 Northern Arctic		15 Arctic Cordillera		Canada	
		a	b	a	b	a	b	a	b	a	b	a	b	a	b	a	b
Wilderness Areas (>16 000 ha) Class A	1961	4	3 930					2	116							28	13 962
	1966	8	5 328					2	116							32	15 380
	1971	9	5 522	1	2 409	1	54.4	5	200							40	18 202
	1976	12	6 287	1	2 409	1	54.4	5	200					1	2 147	56	25 312
	1981	12	5 841	1	2 409	1	54.4	5	200					1	2 147	57	24 900
	1983	16	6 345	1	2 409	1	54.4	5	200	1	52.0			1	2 147	63	25 506
Unique Natural Areas or Monuments Class C	1961	2	104			1	1.6	1	0.1							10	107
	1966	3	112			1	1.6	1	0.1							12	115
	1971	4	112			1	1.6	4	2.6							20	137
	1976	5	112			1	1.6	4	2.6							25	153
	1981	8	211			2	4.3	4	2.6							30	256
	1983	9	246			2	4.3	4	2.6							31	291
Natural Environment Recreation Areas (>200 ha) Class D	1961	28	4 828			10	18.3	4	3.2							88	5 262
	1966	43	5 454			14	22.2	5	3.7							127	6 072
	1971	62	5 972			22	24.5	8	22.7							179	6 829
	1976	77	6 165			30	41.4	19	26.8							243	7 118
	1981	84	6 368			31	58.1	28	32.7							271	7 421
	1983	84	6 368			31	58.1	29	33.0							279	7 442

a: number.

b: area (thousands of hectares).

[1]These categories are based on the classes defined for and used by the Federal-Provincial Parks Conference in its annual compilation of parks data.

[2]1983 data where available.

Source: Various federal and provincial parks authorities.

Table 7.9
Federal and Provincial Parks Showing Extent of Fully Protected Areas, 1983

Protected Area	Classification[1]	British Columbia		Alberta		Saskatchewan		Manitoba		Ontario		Quebec	
		a	b	a	b	a	b	a	b	a	b	a	b
Wilderness Areas (> 16 000 ha) Class A	A	31	4 822	8	5 862	1	387	1	298	4	3 106	5	4 901
	A1	26	3 469	6	1 905	1	387	1	298	3	2 919	2	78.4
	A1/A as %	84	72	75	32	100	100	100	100	75	94	40	1.6
Unique Natural Areas or Monuments Class C	C	66	4.1	8	10.3	15	34.3	2	1.1	14	3.5	10	250
	C1	66	4.1	8	10.3	13	19.9	1	1.0	13	2.0	10	250
	C1/C as %	100	100	100	100	87	58	50	91	93	57	100	100
Natural Environment Recreation Areas (>200 ha) Class D	D	79	170	19	554	37	521	1	1 022	70	1 334	24	4 489
	D1	78	170	15	113	0	0	0	0	68	413	9	193
	D1/D as %	99	100	79	20	0	0	0	0	97	31	38	4.3

Protected Area	Classification[1]	New Brunswick		Nova Scotia		Prince Edward Island		Newfoundland		Yukon		Northwest Territories		Canada	
		a	b	a	b	a	b	a	b	a	b	a	b	a	b
Wilderness Areas (> 16 000 ha) Class A	A	2	43.1	2	133			3	321	1	2 202	3	3 609[2]	61	25 683
	A1	2	43.1	2	133			2	234	1	2 202	2	2 624	48	14 292
	A1/A as %	100	100	100	100			67	73	100	100	67	73	79	56
Unique Natural Areas or Monuments Class C	C	8	0.2			3	0.2	15	2.2			1	0.01	142	306
	C1	0	0			3	0.2	15	2.2			0	0	129	290
	C1/C as %	0	0			100	100	100	100			0	0	91	95
Natural Environment Recreation Areas (>200 ha) Class D	D	6	19.4	4	2.2	4	3.0	21	19.7			5	67.2	285	8 202
	D1	0	0	0	0	4	3.0	21	19.7			0	0	195	911
	D1/D as %	0	0	0	0	100	100	100	100			0	0	68	11

a: number.

b: area (thousands of hectares)

[1]The classification letters A, C, D represent all areas within the specified class whether they are fully protected, partially protected or set aside for multiple use. The classification symbols A1, C1, D1 represent those areas within each class that are fully protected and dedicated to outdoor recreation and nature study only. (See also Table 7.8.)

[2]Includes part of Wood Buffalo National Park.

Source: Federal-Provincial Parks Conference, May 1983 compilation.

tion on Wetlands of International Importance Especially as Waterfowl Habitat, which came into force in 1975. (Canada became a participant in 1981.) Canada has now officially nominated and had accepted a number of world heritage sites and wetlands, the number and size of which are shown in Table 7.11. Some of these areas are already included in Table 7.8 or Table 7.10. The three largest world heritage sites nominated by Canada were Wood Buffalo National Park (Taiga Plain), Kluane National Park (Boreal Cordillera) and Nahanni National Park (Tundra Cordillera). The four largest wetlands of international importance nominated by Canada were the Queen Maud Gulf and Dewey Soper Migratory Bird Sanctuaries (Southern Arctic), the whooping crane summer refuge (Taiga Plain) and the Old Crow Flats (Tundra Cordillera). The Canadian nominations to the wetlands list account for about 50 per cent of the total area so designated by all countries.

ASSESSMENT

The very vastness of the country would preclude a detailed spatial assessment of land use change in Canada. The human predilection for restructuring the environment to suit human needs can, and does, have significant effects on ecosystems well beyond what could be inferred by merely identifying the area of land use change. For example, roads constructed into hitherto inaccessible wilderness could rapidly alter wildlife species composition, and large-scale hydroelectric projects could drastically alter downstream aquatic ecosystems. It is in this wider context that data have been documented in this chapter, emphasizing land use change associated with industrial and urban expansion and the response of governments to protect lands from commercial exploitation (for example, by establishing parks).

Land use changes related to socio-economic

Table 7.10
Wildlife Areas, Bird Sanctuaries and Ecological Reserves by Ecozone, 1961-1983

Protected Area Category	To Year	1 Tundra Cordillera		2 Boreal Cordillera		3 Pacific Maritime		4 Montane Cordillera		5 Boreal Plain		6 Taiga Plain		7 Prairie		8 Taiga Shield	
		a	b	a	b	a	b	a	b	a	b	a	b	a	b	a	b
Wildlife Areas/ Refuges	1961																
	1966									3	316			1	1.8		
	1971									20	430			23	9.9		
	1976					4	0.5	2	1.2	31	469			40	41.0		
	1981					5	0.5	2	1.2	33	473			77	109		
	1983					5	0.5	2	1.2	34	473			78	109		
Bird Sanctuaries	1961					3	2.1	2	0.8	4	34.9			17	73.6		
	1966					3	2.1	2	0.6	11	63.0			27	139	1	0.1
	1971					4	2.7	2	0.6	11	63.0			27	138	1	0.1
	1976					4	2.7	2	0.6	11	61.7			27	138	1	0.1
	1981					4	2.7	2	0.6	11	61.7			27	132	1	0.1
	1983					4	2.7	2	0.6	11	61.7			26	131	1	0.1
Biosphere/ Ecological Reserves[1]	1961																
	1966																
	1971					19	11.9	8	1.3	1	0.3						
	1976			5	39.1	33	24.9	34	16.1	4	14.9	1	0.1				
	1981			6	55.0	48	73.2	49	19.6	8	16.8	2	0.3				
	1983			6	55.0	49	74.5	77	49.9	163	114	7	24.4	90	29.0	1	25.9

Protected Area Category	To Year	9 Boreal Shield		10 Hudson Bay Plain		11 Mixed-Wood Plain		12 Atlantic Maritime		13 Southern Arctic		14 Northern Arctic		15 Arctic Cordillera		Canada	
		a	b	a	b	a	b	a	b	a	b	a	b	a	b	a	b
Wildlife Areas/ Refuges	1961	1	2.5													1	2.5
	1966	1	2.5					1	0.5							6	321
	1971	1	2.5			1	46.9	7	5.6							52	495
	1976	1	5.8	1	522	1	46.9	12	7.5							92	1 094
	1981	1	5.8	2	2 400	1	46.9	17	8.2							138	3 044
	1983	1	5.8	2	2 400	1	46.9	17	8.2							140	3 045
Bird Sanctuaries	1961	9	223	4	56.1	12	13.6	10	55.2	6	7 749	4	2 208	1	0.3	72	10 416
	1966	20	292	4	56.1	12	13.6	10	55.2	6	7 749	4	2 208	2	1 089	102	11 666
	1971	21	293	4	56.1	13	13.7	10	55.2	6	7 749	4	2 208	2	1 089	105	11 667
	1976	21	292	4	56.1	14	13.7	10	55.2	6	7 749	5	2 209	2	1 089	107	11 666
	1981	21	292	4	56.1	14	13.7	10	55.2	6	7 749	5	2 209	2	1 089	107	11 660
	1983	20	292	4	56.1	14	13.7	10	55.2	6	7 749	5	2 209	2	1 089	105	11 658
Biosphere/ Ecological Reserves[1]	1961																
	1966																
	1971	3	0.2			3	0.2									34	13.9
	1976	5	1.2			5	0.3									87	96.6
	1981	6	1.2			7	0.8									126	167
	1983	6	1.2			7	0.8									406	375

a: number.

b: area (thousands of hectares).

[1]Ecological reserves data for Alberta (contributing to Ecozones 4, 5, 6, 7 & 8) all assigned to 1981 year because specific dates of establishment were not available.

Source: Various federal and provincial authorities.

Table 7.11
Areas Nominated by Canada as World Heritage Sites and Wetlands of International Importance
(as of 1984)

Ecozone	Designated World Heritage Sites		Designated Wetlands of International Importance	
	No.	Area (thousands of hectares)	No.	Area (thousands of hectares)
1 Tundra Cordillera	1	477	1	617
2 Boreal Cordillera	1	2 201		
3 Pacific Maritime	1	0.1	1	0.5
4 Montane Cordillera	1	†		
5 Boreal Plain			1	321
6 Taiga Plain	1	4 481	2	2 011
7 Prairie	2	7	2	39
8 Taiga Shield				
9 Boreal Shield	1	8		
10 Hudson Bay Plain			1	33
11 Mixed-Wood Plain			2	14
12 Atlantic Maritime			3	4
13 Southern Arctic			3	7 316
14 Northern Arctic			1	296
15 Arctic Cordillera				
Total	8	7 174	17	10 651

†Less than one hectare.
Source: Personal Communications, D. Gillespie, Canadian Wildlife Service, and H. Eidsvik, Parks Canada, Environment Canada, 1984.

decisions imply choices of alternative uses, and these in turn are influenced by highly subjective values. In all modern industrial states there has been a proliferation of rules about how land can be used, with increasing requirements for environmental impact studies of large-scale physical restructuring projects.

Data on transportation networks show that since 1960 there has been a slight decrease in railroads but a substantial growth in paved roads. However, the more spectacular growth has been in the energy transport network, with substantial extension of electrical transmission lines and oil and gas pipelines. The growth in scale has meant widening rights-of-way corridors and extending the area of environmental disturbance, e.g., urban and inter-urban autoroutes and high-voltage transmission lines. (The latter provided the technical breakthrough for hydro development in the Taiga Shield.)

Between 1921 and 1981 the number of registered dams in Canada increased by 15 times (to 576), and total storage capacity multiplied more than 50 times. The greatest growth in any decade occurred between 1971 and 1981, when hydro development moved into the Taiga Shield ecozone.

Built-on land area in 1981 was estimated at 5.8 million hectares, a growth of 70 per cent since 1951. Although a good proportion of built-on land is for transport networks and farmyards, the most significant growth between 1951 and 1981 was the expansion of urban settlements, which grew by approximately 175 per cent.

Although the number and size of designated wilderness areas have doubled since 1961, only a little more than 50 per cent of the area has been fully protected, i.e., dedicated solely to outdoor recreation and nature study. The total area involved amounted to about 25 million hectares. Eight million hectares have been designated as natural environment recreation areas, although only 10 per cent of these are fully protected.

The size and number of wildlife areas/refuges have gown dramatically since 1961, the area now totalling more than 3 million hectares. There has been modest growth in the number and size of bird sanctuaries during the same period, but the overall area is more than 11 million hectares. There are now more than 400 designated biosphere/ecological reserves in Canada, totalling about 375 000 hectares.

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INTRODUCTION

Contaminants in the environment are of concern when their presence or concentration is known or thought to be associated with adverse effects on ecosystems or human health and well-being. Contaminants such as arsenic, lead, mercury and uranium are found in the environment both naturally and as a result of human activities; others, like PCBs, mirex, and DDT are solely man-made. Some compounds may be biological in nature, developing naturally under specific environmental conditions (e.g., mycotoxins in foods).

Contaminants may find their way into the natural environment as a side-effect of an intentional use, such as the application of pesticides and fertilizers. Or they may be released as a by-product of some industrial, commercial or municipal operation, intentionally or by accident.

Quantitative measurements of contaminants in the environment are carried out for different purposes. Measurements may be made to improve basic knowledge about factors such as persistence, mobility and bio-accumulation. Some studies are designed to determine the nature of the transformation processes (physical/chemical changes) that take place in the environment. Cause-effect relationships under different exposure conditions are also studied.

Other quantitative measurements are made as a part of compliance monitoring programs to determine whether prescribed limits have been exceeded. In such instances, the location of sampling sites is usually chosen carefully in relation to the known source(s) of discharge. Prescribed limits are established by government authorities on scientific and socio-economic grounds.

Some quantitative measurement programs are conducted on a regular, systematic basis and are designed primarily to reflect the average (ambient) conditions in the area around the sampling site, as well as changes over time. Sampling frequency varies considerably from program to program. Samples providing data that might apply to human health tend to be taken more frequently. Urban air samples, for example, are often taken more or less continuously. Those that serve to show general trends over time may be taken every few years, e.g., specific contaminants in the eggs of particular birds nesting in selected areas.

During the past 10 to 15 years, sampling and analytical techniques have become more sophisticated. For example, detection limits have, in many cases, been improved ten-fold.The ability to separate chemical compounds has improved dramatically and this has led to the measurement of trace quantities of compounds not previously identified. Methodologies are undergoing continuous development and improvement.

In addition, there is increasing awareness that effects are seldom related directly to a single causative agent. Often, the effect of a particular substance depends on combination with other substances that may also be present (even in trace quantities). Such combined effects can take different forms. There can be additive effects, in which the total effect is simply the sum of the separate effects; antagonistic effects, in which the effect of one substance is reduced by the presence of another; or synergistic effects, where an effect is enhanced by the presence of one or more substances. The range of possible mixtures and relative concentrations is immense, and laboratory testing programs are both costly and time-consuming. Progress in unravelling the intricacies of combined effects is slow.

Along with programs and studies designed to measure contaminants in the environment, attention has been focused on identifying and quantifying specific sources of discharge or release of major contaminants. Known as inventory programs, these are sometimes based on actual discharge rate measurements as required by regulation. In other cases, the information comes from questionnaire surveys to determine the types of services and equipment available. Such information, coupled with engineering data on process efficiencies, permits estimates of discharge rates to be made.

These various studies and programs have resulted in the identification of a long list of contaminants in the environment. The contaminants discussed in this report were selected on the basis of a multi-stage review involving

1. a comparison of various existing lists of priority substances;
2. consultations with experts in various agencies and fields concerning hazard profiles and use patterns; and
3. examination of various databases to determine access to and availability of comparable quantitative data over time.

In order to present an overall view, the data in this chapter have frequently been aggregated and presented in relation to large geographical areas or for the country as a whole. In some cases, it has been possible to provide information based on systematically collected samples, with results averaged over space and/or time and with ranges of values or maximum values to give a better indication of the situation. In other cases, the available data consist of sporadic measurements taken at a few sites that may differ with time and that may or may not be representative of the general geographic area from which they came. A wide variety of data has been used, reflecting different time periods and different geographical configurations.

For this report, data have been examined in relation to the following issues and problems:

1. the problem of excessive nutrients in water systems (i.e., phosphorus and nitrate/nitrite in drainage basins);
2. concerns about the significance of wastewater

discharges to receiving waters (e.g., general indicators such as biochemical oxygen demand and total suspended solids);
3. the acid rain issue (i.e., sulphur dioxide and nitrogen oxides);
4. the general concern about selected pesticides (e.g., DDT, dieldrin and the special case of dioxins, which are found as impurities in certain pesticides and industrial organic compounds);
5. the general concern about selected industrial organic compounds (e.g., PCBs and mirex);
6. concerns about selected inorganic substances (e.g., arsenic, cadmium, lead and mercury) found in nature but also in higher concentrations as a result of human activity; and
7. concerns about nuclear radiation (e.g., radioactivity from atmospheric nuclear testing).

WATER QUALITY

Variations in water quality occur naturally as a result of underlying geological formations, nearby vegetation and climate. The problem is to distinguish natural background levels of 'contamination' from those originating from waste discharges of municipalities, industries, resource exploitation and agricultural runoff. Water quality requirements vary greatly depending on whether the water is used as a source of drinking water, for recreational purposes, for agricultural purposes, for aquatic life, or for industrial processes and cooling.

Nutrients in Water

An excess of nutrients in a water system shifts the ecological balance and leads to a process called eutrophication. High nutrient levels promote the growth of algae; this is followed by a depletion of dissolved oxygen as a result of the bacterial decomposition of dead algal material. Then anaerobic bacteria appear and convert other wastes into obnoxious gases such as hydrogen sulphide, changing the equilibrium of the ecosystem. Although eutrophication is a natural process, the concern here is the increasing evidence of these processes as a result of human activities.

During the 1960s, extensive studies of the lower Great Lakes, principally Lake Erie, showed that eutrophication was well advanced. The major nutrients contributing to eutrophication were phosphates and nitrates associated with municipal sewage treatment plants, detergents and agricultural runoff. Phosphates were considered to be the most important factor. In Canada, action was taken to reduce the phosphate content of detergents, and emphasis was placed on developing, installing and improving sewage treatment plants.

Although nutrients entering water bodies are soon taken up by growing plants, measurements of phosphates and nitrates in such systems serve as broad indicators of the risk of eutrophication. Values of total phosphorus greater than 0.1 milligrams per litre (mg/L) are known to contribute to accelerated algae growth in flowing water (for lakes, values above 0.025 mg/L). Nitrate and nitrite are usually measured together, with nitrite occurring at about $\frac{1}{1000}$ of the concentration of nitrate. Nitrate and nitrite are of interest not only because of their contribution as nutrients but also because they can be harmful to human health at sufficiently high levels. A specific concentration guideline figure has not been established for nitrate in relation to algal growth, but the guideline for the maximum acceptable concentration of nitrate/nitrite in drinking water has been set at 10 mg/L.

Water Quality Trends

Water quality monitoring programs encompassing most of Canada's major surface waters have been under way for a number of years. Sampling stations are located with a view to observing water quality conditions in rivers and streams generally, rather than studying local or regional conditions in detail. Samples are usually collected monthly and analyzed for a wide range of chemical, physical and biological parameters. Samples collected at selected sites from time to time are also analyzed for toxic substances, including trace elements, pesticides, and polychlorinated biphenyls (PCBs). Results are stored in the National Water Quality Data Bank (NAQUADAT). Individual results are recorded by watershed, sampling site and date, and by a control number identifying the laboratory method of analysis.

For presentation of NAQUADAT water quality data in this report, the watersheds have been grouped together to form 22 major drainage basins covering the whole country. The delineation of these drainage basins is consistent with the system used by the Water Survey of Canada. In areas of high population density the smaller sub-basins were retained. Basins were aggregated to form larger basins as population density decreases in more sparsely settled parts of the country. A listing of these major drainage basins is given in Table 8.1. All NAQUADAT time trends in this report are based on four three-year periods: 1971-73, 1974-76, 1977-79 and 1980-82.

Phosphorus and Nitrate in River Basins and the Great Lakes

NAQUADAT files contain data on total phosphorus and on nitrate/nitrite. The data on total phosphorus measurements for each major drainage basin are summarized in Table 8.2 and mapped in Figure 8.1. The number of measurements recorded, the number and percentage that exceeded 0.05 mg/L, and the number and percentage that exceeded 0.1 mg/L are shown.

These data suggest a wide fluctuation in the fre-

Table 8.1
Major Drainage Basins Used for Compiling NAQUADAT Data

No.	Major Drainage Basin	Area (km^2)
1	Atlantic Ocean Coastal Drainage	340 260
2	Gulf of St. Lawrence Coastal Drainage	219 065
3	Bay of Fundy Coast-Saint John River Drainage	62 590
4	St. Lawrence River Drainage	210 590
5	Ottawa River Drainage	146 685
6	Lake Ontario Shore Drainage	29 695
7	Lake Erie and Lake St. Clair Shores Drainage	23 550
8	Lake Huron Shore Drainage	92 520
9	Lake Superior Shore Drainage	101 795
10	Hudson Bay and Ungava Bay Drainage	2 526 070
11	Nelson River Drainage	90 365
12	Lake Winnipeg Shore Drainage	336 975
13	Assiniboine River Drainage	161 845
14	Saskatchewan River Drainage	409 100
15	Mackenzie River Drainage	1 795 365
16	Arctic Ocean Coastal Drainage	3 054 525
17	Columbia River Drainage	103 935
18	Fraser River Drainage	235 135
19	Yukon River Drainage	334 805
20	Pacific Ocean, North Coastal Drainage	258 120
21	Pacific Ocean, South Coastal Drainage	78 285
22	Milk River Drainage	26 135

Source: Statistics Canada, *Human Activity and the Environment*, Annual Catalogue 11-509, 1986.

quency of high total phosphorus levels (>0.1 mg/L) over the 12-year period. The locations and the number of samples varied over time, and the increased percentage of high phosphorus levels in prairie rivers in the 1980-82 period may reflect increased sampling in areas of higher levels (e.g., Lake Winnipeg drainage and Assiniboine River) rather than actual increases. Nonetheless, the Saskatchewan River basin includes a good part of the prairie wheat-growing area where major increases in the use of fertilizers have been recorded during this period.

In the Great Lakes area, however, there were significant reductions in the total phosphorus loading from municipal sources between 1970 and 1982. Furthermore, measurements of total phosphorus in Lake Ontario from another survey over the same period show significant reductions, from a mean level of about 0.027 mg/L to about 0.014 mg/L.

Similar data for nitrate/nitrite are presented in Table 8.3 and Figure 8.2. Here, the computer file search was based on the maximum acceptable drinking water concentration (>10 mg/L) and >1 mg/L. The figures for the earlier periods (1971-73 and 1974-76) suggest that nitrate/nitrite were being detected in most river basins at the >1 mg/L level, with a range of detection of between 1 and 10 per cent of the samples. River basins where this level of concentration was found in 10 per cent of the samples are the Gulf of St. Lawrence, the Bay of Fundy Basin, the Assiniboine River, and the Fraser River. The 1974-76 data showed a considerable decrease in the proportion of samples that exceeded the search parameters. However, the number of samples tested for nitrate/nitrite was reduced from 20 000 to 15 000, and the smaller sample may have affected the results. The later data (1977-79 and 1980-82) are clearly not comparable to the earlier period because of the drastic reduction in the number of samples taken — on the order of one-tenth.

WASTEWATER DISCHARGES

Wastewater flows usually contain a complex mixture of substances. Several measures have therefore been developed to serve as general indicators of water quality. Measurements of the biochemical oxygen demand (BOD) and of the total suspended solids (TSS) are two such indicators. In terms of municipal sewage, the presence or absence of wastewater treatment facilities and the type of treatment system serve as stress indicators of the pollution risk to local water bodies.

Municipal Wastewater Treatment

Data on the nature and extent of municipal wastewater treatment systems in Canada are maintained by Environment Canada in collaboration with provincial inventory programs. Data for 1975 and 1985 for Canada as a whole are summarized in Table 8.4. The data are presented in relation to communities of four different population sizes. It is apparent that the overall picture did not change significantly between 1975 and 1985. Nearly two-thirds of the people living in small communities (population less than 2 500) are not served by sewage treatment plants. This may reflect a reluctance to install these services in small communities because of the high cost per capita. However, septic tanks are the preferred method of sewage disposal in many small communities and rural homes. Sewage disposal directly into rivers, lakes or the sea is still practised by many communities where the self-cleansing properties of water are considered sufficient, or at least benefits relative to costs appear to favour continuing the traditional practice. Nevertheless, even in the very large communities (population more than 100 000), 25 per cent of the population is not served by sewage treatment facilities.

It is likely that much of the money that has been spent on wastewater treatment in recent years has gone to upgrading existing systems, not to installing new treatment plants. This could account for the small change between 1975 and 1985.

As of 1985, of 1 750 wastewater treatment systems identified, 70 were classed as 'primary', 537 as 'secondary', 972 as 'lagoons', 75 as 'communal septic tanks', and 96 as 'other'. Table 8.5 presents a more detailed analysis of the 1985 data, with the information broken down by jurisdiction. Here it can be seen that the percentage distribution of the population

Text continues on page 165.

Table 8.2
NAQUADAT Water Quality Data — Phosphorus[1]

Drainage Basin	1971-73			1974-76			1977-79			1980-82		
	Number of Samples	% of samples >0.05 mg/L	% of samples >0.1 mg/L	Number of Samples	% of samples >0.05 mg/L	% of samples >0.1 mg/L	Number of Samples	% of samples >0.05 mg/L	% of samples >0.1 mg/L	Number of Samples	% of samples >0.05 mg/L	% of samples >0.1 mg/L
1 Atlantic Coast	—			208	3.4	2.9	598	2.2	1.0	1 555	11.1	5.6
2 Gulf of St. Lawrence	—			801	23.5	8.5	399	9.0	1.8	422	8.1	2.6
3 Bay of Fundy	21	0	0	1 287	12.0	5.6	1 218	13.1	6.0	669	7.2	3.3
4 St. Lawrence	417	24.9	7.0	443	4.5	1.8	628	12.6	2.7	595	43.2	13.3
5 Ottawa River	773	17.7	7.4	34	5.9	5.9	428	10.7	4.0	19	73.7	0
6 Lake Ontario	65	13.8	6.2	791	0.5	0	324	4.6	2.2	—		
7 Lake Erie/St. Clair	90	57.8	32.2	138	31.9	10.9	88	36.4	20.5	14	28.6	7.1
8 Lake Huron	79	0	0	929	0.3	0	35	20.0	5.7	5	20.0	20.0
9 Lake Superior	18	5.6	0	400	0.8	0.2	15	13.3	13.3	464	8.6	2.8
10 Hudson Bay	196	4.1	0.5	486	13.0	3.5	641	18.1	3.7	170	32.9	11.2
11 Nelson River	192	7.3	3.6	127	11.0	4.7	29	20.7	3.4	12	33.3	25.0
12 Lake Winnipeg	469	27.7	11.3	447	45.4	30.0	1 966	86.0	76.0	2 744	84.0	67.3
13 Assiniboine River	1 207	94.8	86.3	1 768	95.2	82.2	618	96.3	87.1	2 176	99.8	98.3
14 Saskatchewan River	1 545	16.1	9.3	2 608	9.3	3.8	1 039	24.8	12.0	761	34.8	16.8
15 Mackenzie River	812	23.5	14.8	1 626	14.9	7.6	280	28.6	20.4	377	25.7	15.4
16 Arctic Ocean	4	0	0	199	22.6	17.6	101	16.8	9.9	67	7.5	1.5
17 Columbia River	1 017	45.3	28.6	1 381	5.3	2.6	1 221	1.1	0.7	381	23.1	8.7
18 Fraser River	500	42.4	14.2	997	8.8	4.5	—			11	90.9	81.8
19 Yukon River	11	63.6	0	27	18.5	3.7	87	0	0	55	14.5	9.1
20 Pacific North Coast	58	6.9	5.2	52	38.5	21.2	—			217	71.4	59.4
21 Pacific South Coast	47	0	0	21	19.0	9.5	—			3	33.3	0
22 Milk River	11	27.3	9.1	169	46.2	29.0	311	48.2	31.2	199	28.6	18.6
Total	7 532	36.2	24.6	14 937	21.3	14.6	10 026	33.1	25.0	10 916	53.1	42.3

[1]NAQUADAT parameter codes 15405, 15406 and 15413 were combined to produce this table. The codes refer to a method of colourimetric analysis and filtration to determine total phosphorus. Total phosphorus includes a mineral phosphate portion that is not readily absorbed by algae. Measurements in the Mackenzie River, Yukon River and Pacific North Coast Basins consist largely of the mineral phosphate portion.

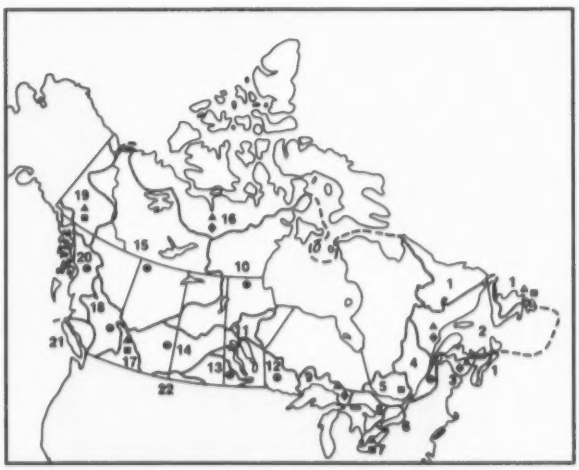
Source: Environment Canada, NAQUADAT database.

Figure 8.1
Phosphorus in Major Drainage Basins of Canada

1971-73

1977-79

1974-76



1980-82

- ● > 0.1 mg/L in > 10% of samples
- ▲ > 0.1 mg/L in < 10% of samples
- ■ > 0.05 mg/L in > 10% of samples
- ◆ > 0.05 mg/L in < 10% of samples
- ★ < 0.05 mg/L in all samples

Minimum of 6 samples per drainage basin

770 0 770 1540 kilometres

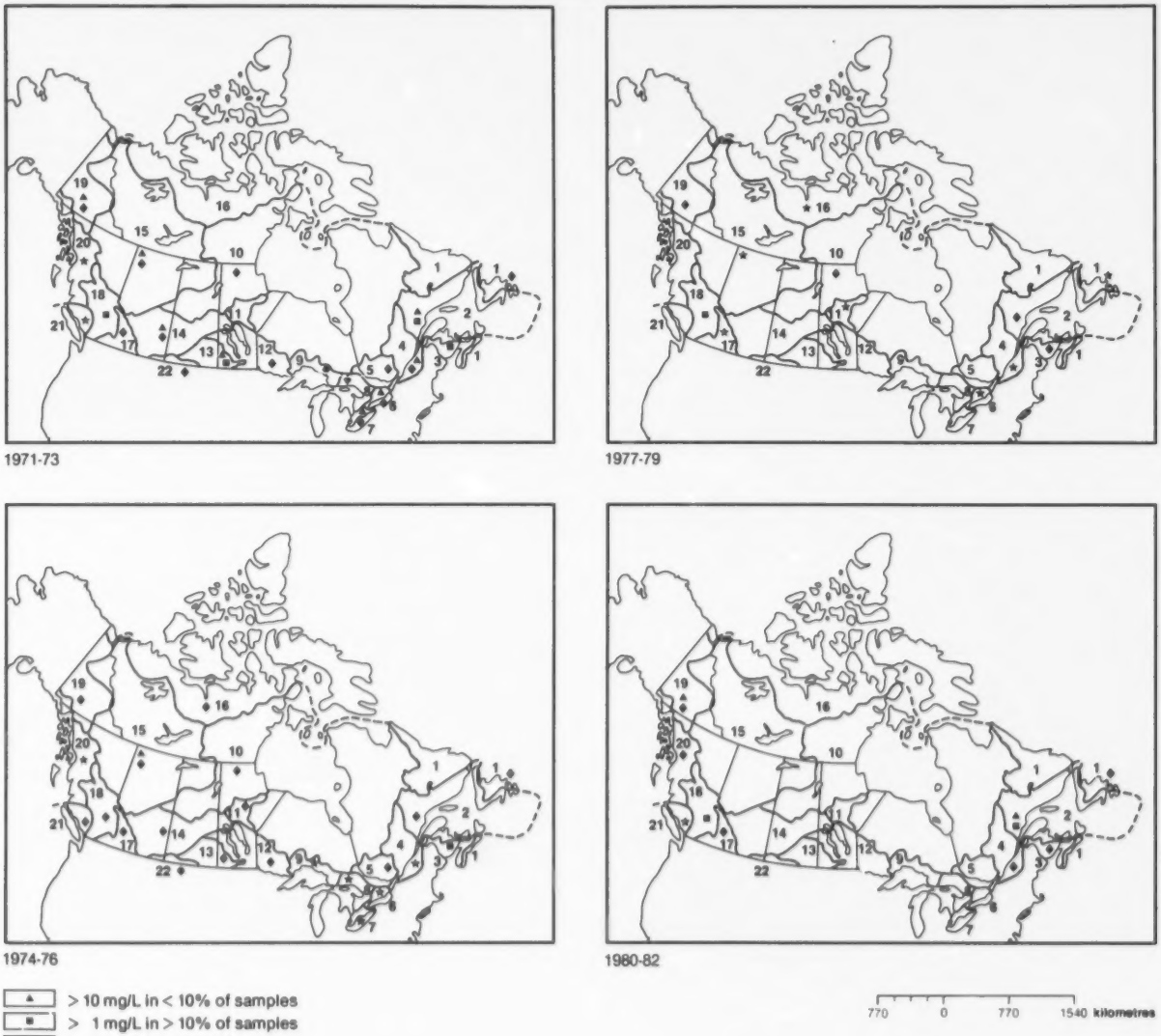
Source: Environment Canada, NAQUADAT database.

Table 8.3
NAQUADAT Water Quality Data — Nitrate/Nitrite[1]

Drainage Basin	1971-73			1974-76			1977-79			1980-82		
	Number of Samples	% of samples >1 mg/L	% of samples >10 mg/L	Number of Samples	% of samples >1 mg/L	% of samples >10 mg/L	Number of Samples	% of samples >1 mg/L	% of samples >10 mg/L	Number of Samples	% of samples >1 mg/L	% of samples >10 mg/L
1 Atlantic Coast	1 185	2.6	0	478	4.2	0	86	0	0	704	2.4	0
2 Gulf of St. Lawrence	3 470	10.3	0.2	1 470	4.4	0	164	4.3	0	131	22.1	1.5
3 Bay of Fundy	4 262	10.2	0	1 504	10.3	0	175	4.0	0	162	3.8	0
4 St. Lawrence River	823	0.7	0.1	575	0	0	361	0	0	467	0.2	0
5 Ottawa River	425	2.1	0	22	9.1	0	1	0	0	3	0	0
6 Lake Ontario	72	2.8	1.4	919	0	0	19	0	0	—		
7 Lake Erie/St. Clair	1 112	4.6	0.2	212	0	0	4	0	0	1	0	0
8 Lake Huron	388	0.8	0	57	0	0	—			4	0	0
9 Lake Superior	83	1.2	0	511	0	0	1	0	0	2	0	0
10 Hudson Bay	446	0.7	0	371	0.5	0	57	1.8	0	—		
11 Nelson River	260	4.6	0	148	1.4	0	28	0	0	—		
12 Lake Winnipeg	723	1.9	0	358	7.8	0	1	0	0	—		
13 Assiniboine River	1 100	10.7	1.9	1 341	4.3	0.2	3	0	0	—		
14 Saskatchewan River	2 058	1.9	0.1	2 618	0.8	0	1	0	0	—		
15 Mackenzie River	1 143	6.0	0.6	1 633	4.3	0	109	0	0	—		
16 Arctic Ocean	23	0	0	194	1.5	0	11	0	0	—		
17 Columbia River	1 450	9.3	0	1 338	0.1	0	365	0	0	888	0.5	0
18 Fraser River	689	11.6	0	1 013	0.7	0	12	41.7	0	50	42.0	0
19 Yukon River	176	6.2	0.6	149	5.4	0	156	4.5	0	161	3.1	0.6
20 Pacific North Coast	210	0	0	52	0	0	—			201	0.5	0
21 Pacific South Coast	184	0	0	306	5.6	0	1	0	0	10	0	0
22 Milk River	49	2.0	0	145	2.1	0	—			—		
Total	20 331	6.8	0.2	15 414	3.0	0.2	1 555	1.7	0	2 784	3.1	0.1

[1]NAQUADAT parameter codes for dissolved nitrate and nitrite, 07105 through 07110, were combined to produce this table.
Source: Environment Canada, NAQUADAT database.

Figure 8.2
Nitrate/Nitrite in Major Drainage Basins of Canada


1971-73
1977-79
1974-76
1980-82
▲ > 10 mg/L in < 10% of samples
■ > 1 mg/L in > 10% of samples
◆ > 1 mg/L in < 10% of samples
★ < 1 mg/L in all of samples
Minimum of 6 samples per drainage basin
770 0 770 1540 kilometres

Source: Environment Canada, NAQUADAT database.

Table 8.4
Canadian Population Served by Municipal Wastewater Treatment Systems, 1975 and 1985

		Population Size Groups				
	Date	<2 500	2 501-10 000	10 001-100 000	>100 000	Total
Number of communities surveyed	1975	1 990	516	245	29	2 780
	1985	2 622	577	254	30	3 483
Total population covered by survey	1975	1 919 465	2 533 755	7 070 792	8 483 888	20 007 900
	1985	2 182 041	2 861 493	7 431 039	8 951 540	21 426 113
Percentage of population served by sewage treatment systems	1975	32.8	43.8	47.6	75.3	57.5
	1985	36.3	46.8	47.6	74.3	57.5

Source: Environment Canada, National Inventory of Municipal Waterworks and Wastewater Systems in Canada, 1975, 1985.

Table 8.5
Population Served by Municipal Wastewater Treatment Systems

	Population Size Groups	British Columbia	Alberta	Saskatchewan	Manitoba	Ontario	Quebec[1]	New Brunswick
Number of communities surveyed		50	354	115	258	182	1 167	61
Population surveyed	<2 500	63 164	152 693	105 881	115 577	232 986	1 124 806	78 259
% Population served by sewage treatment		68.6	98.3	96.6	66.3	63.8	9.9	81.9
Number of communities surveyed		44	48	18	15	150	220	21
Population surveyed	2 501-10 000	234 090	219 889	78 560	74 019	817 415	1 025 255	109 998
% Population served by sewage treatment		81.1	100	98.7	97.6	53.2	15.6	83.8
Number of communities surveyed		37	13	5	3	86	88	6
Population surveyed	10 001-100 000	1 179 500	345 444	109 437	71 639	2 411 456	2 665 600	221 643
% Population served by sewage treatment		73.5	91.5	98.9	98.4	77.6	3.6	41.8
Number of communities surveyed		3	2	2	1	17	4	
Population surveyed	>100 000	699 000	1 179 899	317 194	577 923	4 179 751	1 869 773	
% Population served by sewage treatment		84.5	100	99.9	100	94.3	2.6	
Number of communities surveyed		134	417	140	277	435	1 479	88
Population surveyed	Total	2 175 754	1 897 925	611 072	839 158	7 641 608	6 685 434	409 900
% Population served by sewage treatment		77.7	98.3	99.0	95.0	83.7	6.2	60.7

	Population Size Groups	Nova Scotia	Prince Edward Island	Newfoundland	Yukon	Northwest Territories	Canada
Number of communities surveyed		73	21	287	7	47	2 622
Population surveyed	<2 500	61 596	20 148	193 627	4 959	28 345	2 182 041
% Population served by sewage treatment		74.7	84.0	12.0	77.8	20.4	36.3
Number of communities surveyed		29	1	28		3	577
Population surveyed	2 501-10 000	149 971	9 439	127 249		15 608	2 861 493
% Population served by sewage treatment		35.3	100	10.8		100	46.8
Number of communities surveyed		7	1	7	1		254
Population surveyed	10 001-100 000	205 249	28 000	176 142	16 929		7 431 039
% Population served by sewage treatment		21.1	100	15.2	88.6		47.6
Number of communities surveyed		1					30
Population surveyed	>100 000	128 000					8 951 540
% Population served by sewage treatment		0					74.3
Number of communities surveyed		110	23	322	8	50	3 483
Population surveyed	Total	544 816	57 587	497 018	21 888	43 953	21 426 113
% Population served by sewage treatment		26.1	94.4	12.8	86.2	52.5	57.5

[1]Quebec data are for 1981.
Source: Environment Canada, National Inventory of Municipal Waterworks and Wastewater Systems in Canada, 1985.

Table 8.6
Water Pollution Abatement, Canadian Pulp and Paper Industry, 1980

	Atlantic Region	Quebec Region	Ontario Region	Western & Northern Region	Pacific Region
Number of Mills Assessed	19	47	29	7	25
Average Daily Production (tonnes)	9 482	21 391	14 289	2 860	16 826
TSS (kg/tonne production)	21	26	14	13	19
100% Compliance Target (kg/tonne) based on 1980 production	11	13	12	10	9
BOD_5 (kg/tonne production)	49	66	51	15	23
100% Compliance Target (kg/tonne) based on 1980 production	35	41	34	12	23

Source: Environment Canada, *Status Report on Abatement of Water Pollution from the Canadian Pulp and Paper Industry (1980)*, EPS 3-WP-82-3, July 1982.

served by sewage treatment systems is very uneven across Canada. The three lowest overall figures are 6.2 per cent in Quebec (1981), 12.8 per cent in Newfoundland and 26.1 per cent in Nova Scotia. In Newfoundland and Nova Scotia much of the wastewater is discharged into the sea, placing nearby shellfish grounds at risk from pollution.

Industrial Wastewater Treatment

In developing industrial water pollution control measures, it has been the practice in Canada to distinguish between new and old plants in setting compliance levels. This flexible approach allows far more stringent controls to be built into the specifications of new plants but permits older plants to continue operations. This process is designed to take into account economic factors as well as environmental concerns. Wastewater controls are also usually expressed in relation to the production capacity of the industry (e.g., kilograms of permitted waste discharge per tonne of output) rather than the assimilative capacity of receiving waters.

A number of industrial sectors contribute significantly to water pollution. Three industries have been given special attention through effluent regulation: pulp and paper, petroleum refining, and food processing.

Table 8.6 provides a summary statement of the compliance status of pulp and paper mills in 1980. The pollution loading indicators used are BOD* and TSS.**

Of the 127 mills assessed (out of a total of 152 mills), 71 (56 per cent) were in compliance with respect to TSS, and 93 (73 per cent) were in compliance with respect to BOD_5. Overall, the 1980 average discharge of TSS was 20 kg/tonne of production, which represents a 59-per cent reduction from the 1969 average discharge of 49 kg/tonne.

For BOD_5, the overall average in 1980 was 47 kg/tonne of production, which represents a 40-per cent reduction from the 1969 figure of 78 kg/tonne. Evaluation on a regional basis shows that there is room for continued improvement with respect to the TSS indicator by the mills in the Atlantic, Quebec and Pacific regions. Mills in the Atlantic, Quebec and Ontario regions will have to reduce their BOD_5 discharge if the 100-per cent compliance target is to be reached.

Table 8.7 shows the compliance status of water pollution abatement for the petroleum refining industry. Of 36 operating refineries in Canada, one had no discharge during the year, five were in compliance 100 per cent of the time, 17 exceeded the discharge limits up to 5 per cent of the time, and 13 exceeded the discharge limits more than 5 per cent of the time. On a regional basis, with the exception of refineries in the Quebec region, the actual discharges of oil and grease and suspended solids were well below authorized levels. Even for Quebec, the average discharges of oil and grease and suspended solids did not exceed the authorized level by much (20 and 10 per cent respectively). Refineries in all regions were discharging well below authorized levels for phenols, sulphides and ammonia.

ACID RAIN

During the past several years, acid rain has often been cited as the major environmental problem facing eastern North America. Acid rain (including precipitation in the form of snow or fog and fall-out of dry particulate matter) is produced when sulphur dioxide (SO_2) and nitrogen oxide (NO_x*) emissions are converted in the atmosphere to acidic compounds (sulphates and nitrates) and return to earth as precipitation or particulate matter. The effects of acid rain are often felt in areas far from the actual sources of emissions. The term 'long-range transport of airborne pollutants', or LRTAP, is used to describe this phenomenon.

Major sources of sulphur dioxide emissions are thermal-electric power generating plants, non-ferrous

*BOD is a measure of the amount of oxygen needed for bacterial decomposition of organic material over a given period of time. Substances with high BOD deplete water of dissolved oxygen, depriving fish of oxygen. Dead algae are an example of materials with high BOD. BOD_5 is the amount of oxygen used over five days.
**This is a measure of the amount of total suspended solids.

*Nitrogen and oxygen form a number of compounds, collectively abbreviated as NO_x.

Table 8.7
Water Pollution Abatement, Canadian Petroleum Refining Industry, 1980

		Atlantic Region	Quebec Region	Ontario Region	Western & Northern Region	Pacific Region
Number of Refineries		4	7	8	9	7
Reference Crude Rate (1 000 m^3/day)		45.28	87.2	103.3	63.52	27.68
Oil and Grease (kg/1 000 m^3)	Actual	4.3	20.19	5.58	2.6	9.6
	Authorized	15.6	17.2	13.73	16	16.6
Phenols (kg/1 000 m^3)	Actual	0.26	1.29	0.14	0.3	1.4
	Authorized	1.5	1.7	1.37	1.7	1.7
Sulphides (kg/1 000 m^3)	Actual	0.05	0.37	0.05	0.01	0.4
	Authorized	0.51	0.57	0.46	0.6	0.5
Ammonia (kg/1 000 m^3)	Actual	3.3	9.1	4	1.3	4.8
	Authorized	13.6	14.3	12.73	13.7	14
Suspended Solids (kg/1 000 m^3)	Actual	15.99	46.19	15.3	7.9	13.1
	Authorized	37.5	41.2	33.18	38.6	40

Source: Environment Canada, *Status Report on Abatement of Water Pollution from the Canadian Petroleum Refining Industry 1980*, EPS 3-WP-83-3, March 1983.

Table 8.8
Historical Trends in SO_2 and NO_x Emissions

	SO_2 millions of tonnes/year				NO_x millions of tonnes/year			
	U.S.A.		Canada		U.S.A.		Canada	
	Northeast & Midwest[1]	Total	Eastern[2]	Total	Northeast & Midwest[1]	Total	Eastern	Total
1955	10.1	19.0	4.3	4.5	3.8	8.2	0.45	0.64
1965	12.8	22.5	5.5	6.6	5.5	13.1	0.56	0.85
1975[3]	10.3	22.0	4.4	5.3	6.1	16.4	0.99	1.60
1980	8.9	24.1	3.8	4.6	5.5	19.3	1.05	1.75

[1]Includes EPA Regions I, II and V (i.e., Connecticut, Maine, Maryland, New Hampshire, Rhode Island, New York, New Jersey, Illinois, Michigan, Minnesota, Ohio, and Wisconsin).
[2]Includes Manitoba, Ontario, Quebec, New Brunswick, Nova Scotia, Prince Edward Island and Newfoundland.
[3]Canadian data are for 1976.
Source: United States–Canada Memorandum of Intent on Transboundary Air Pollution, Work Group 3B, *Final Report*, June 1982; Environment Canada, Environmental Protection Service, Personal Communication, 1985.

smelting and refining plants, and other industrial processes consuming coal and oil. Major sources of nitrogen oxides are automobile emissions, industrial processes, and power generating plants. Natural sources of sulphur and nitrogen oxides, such as swamps and marshes, contribute an estimated 10 per cent to total SO_2 emissions and perhaps as much as 50 per cent to total NO_x emissions on a global scale. Sulphur compounds can remain in the atmosphere for two to five days. Nitrogen compounds, on average, remain in the upper atmosphere up to two days and are therefore found somewhat closer to emission sources.

Information on trends in the emission of SO_2 and NO_x in the United States and Canada since 1955 is in Table 8.8. Data have been aggregated for each country as a whole and for a selected region in each country. The acid rain problem in Canada has, to date, been predominantly in the east because of prevailing winds; therefore, the regions selected were the north-eastern and midwestern United States and Canada east of the Manitoba-Saskatchewan boundary. These data indicate that SO_2 emissions did not change greatly (especially the regional figures) over the period between 1955 and 1980. There was, however, a substantial increase in NO_x emissions.

A breakdown by source of 1980 emissions in the two countries is in Table 8.9. Electrical utilities predominate as the source of SO_2 in the United States, whereas non-ferrous smelters are the most significant Canadian sources. In both the United States and Canada, transportation is the major contributor to

Table 8.9
Sources of SO_2 and NO_x Emissions, Canada and the United States, 1980

	SO_2 millions of tonnes per year		NO_x[2] millions of tonnes per year	
	U.S.A.	Canada	U.S.A.	Canada
Electrical Utilities	15.8	0.77	5.6	0.26
Residential/Commercial/ Industrial Fuel Combustion	3.2	0.61	4.2	0.34
Non-ferrous Smelters	1.4	2.09[1]		
Transportation	0.8	0.14	8.5	1.08
Other Industrial Processes & Miscellaneous	2.9	1.03	1.0	0.08
Total	24.1	4.64	19.3	1.75

[1]Copper, nickel, lead and zinc smelters only.
[2]NO_x reported as NO_2.
Source: United States–Canada Memorandum of Intent on Transboundary Air Pollution, Executive Summaries of Work Group Reports, February 1983; Environment Canada, Environmental Protection Service, Personal Communication, 1985.

Table 8.10
Percentage Contribution to Wet Sulphate Deposition

Source	North-central Ontario %	South-central Ontario %	Southern Quebec %	Southern Nova Scotia %
Canada	29-32	32-46	35-58	30-34
United States	68-71	54-68	42-65	66-70

Source: Environment Canada, *Acid Rain. The Canadian Perspective* (Ottawa: 1984).

NO_x emissions, although this is a relatively more important source in Canada.

Computer simulation models have been used to link wet sulphate deposition to areas where large sources are located. The accuracy of these models has been verified, within reasonable limits, by correlating computer outputs with field measurements. The relative contribution of Canadian and U.S. sources of SO_2 emissions to wet sulphate deposition in several areas of eastern Canada is shown in Table 8.10.

There is a considerable body of evidence to show that acid rain poses a threat to various economic resources: fisheries, forestry, agriculture and wildlife. All areas subject to acid rain deposition, however, are not equally susceptible. To a large extent, the capacity of a particular area to remain relatively unaffected by acid rain is determined by the composition and natural acidity or alkalinity of the soil and underlying geological formations. The higher the capacity for natural buffering (limestone) in the soil and water, the greater the ability to neutralize acidic compounds. It is possible, therefore, to define regions of high, moderate or low sensitivity to acid rain. Effects will be greatest in high-sensitivity areas exposed to high deposition.[4]

Sulphate deposition has been identified as the dominant factor contributing to the long-term acidification process in eastern Canada. Figure 8.3 is a map of eastern Canada showing annual sulphate deposition. Bearing in mind such factors as changes in measurement methodologies (e.g., siting, sampling techniques, analytical techniques) and fluctuations in annual emissions and in meteorological conditions, this broad deposition pattern adequately reflects the situation during the five-year period from at least 1978 to 1982. This distribution has been used as a basis for preparing Tables 8.11, 8.12 and 8.13, summarizing surface water, agricultural, and forestry areas exposed to various levels of sulphate deposition.

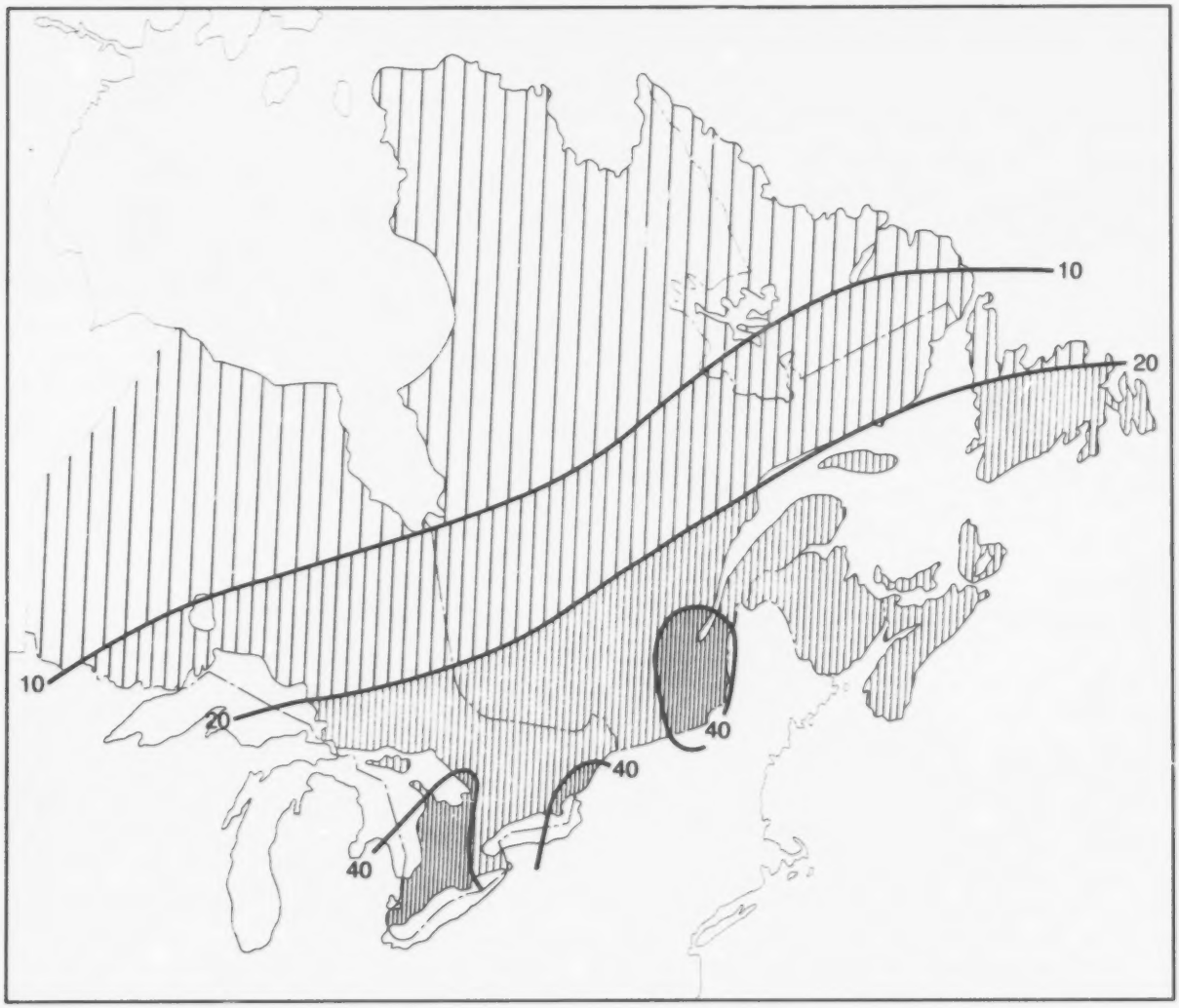
Deposition rates in relation to seasonal conditions are important in evaluating damage caused by acid rain. For example, the sudden loading of water bodies with the winter's accumulation of acidic compounds from melting snow (i.e., acid shock) poses a particularly serious threat to the fragile spring cycle of various aquatic species.

The potential effects of the deposition of acidic compounds on water quality and on aquatic ecosystems appear to be more fully quantified and understood than are its effects on terrestrial ecosystems. Field studies have been conducted under both natural and controlled experimental conditions. Surveys indicate that surface waters that have elevated sulphate levels occur in areas that have high atmospheric deposition of sulphates. These waters exhibit the symptoms of acidification (e.g., lower pH and depletion of fish populations). A decrease in pH is also associated with the increased solubility of the metals aluminum, mercury, cadmium and lead, which are toxic to fish and other aquatic organisms.

For regions receiving sulphate depositions of less than 20 kilograms per hectare per year (kg/ha/y), detrimental chemical or biological effects have not been observed. For regions receiving sulphate deposition of between 20 and 30 kg/ha/y, there is evidence of chemical alteration and acidification. For regions experiencing loading greater than 30 kg/ha/y, the long-term chemical and/or biological effects, as well as the short-term effects on non-alkaline surface waters, can be expected to be serious; such effects have been documented.

A summary of the surface waters in eastern Canada that receive sulphate depositions of more than 10 kg/ha/y is provided in Table 8.11. Overall, nearly 90 per cent of the surface water area is in the moderate- to high-sensitivity class, and about 55 per cent of the surface water area is exposed to sulphate depositions greater than 20 kg/ha/y. About 45 per cent falls into both groups, i.e., above 20 kg/ha/y and moderate to high sensitivity; this represents the area at greatest risk. Although there are no data on the full effects of acid rain on aquatic life, there have been

Figure 8.3
Annual Sulphate Deposition Regime for Eastern Canada Based on 1980 Data



Source: United States-Canada Memorandum of Intent on Transboundary Air Pollution, Working Group 1, *Final Report*, January 1983.

Table 8.11
Surface Water Area in Eastern Canada, by Sensitivity and Deposition

	Sulphate Deposition (kg/ha/y)	Area[1] and Percentage of Total							
		Sensitivity to Acid Deposition[2]							
		High		Moderate		Low		Total[4]	
		km²	%	km²	%	km²	%	km²	%
Ontario	10-20	11 254	(12)	4 142	(4)	1 672	(2)	17 048	(18)
	20-40	8 452	(9)	1 890	(2)	2 120	(2)	12 462	(13)
	>40	408	(1)	98	(1)	408	(1)	914	(1)
Quebec	10-20	20 474	(22)	2 532	(3)	2 972	(3)	25 978	(27)
	20-40	10 137	(11)	730	(1)	3 006	(3)	13 873	(15)
	>40	NA		456	(1)	252	(1)	708	(1)
Maritimes[3]	10-20								
	20-40	8 719	(9)	13 447	(14)	1 482	(2)	23 648	(25)
	>40								
Overall	10-20	31 728	(34)	6 674	(7)	4 644	(5)	43 046	(45)
	20-40	27 308	(27)	16 067	(17)	6 608	(7)	49 983	(53)
	>40	408	(1)	554	(1)	660	(1)	1 622	(2)
Total		59 444	(63)	23 295	(25)	11 912	(13)	94 651	(100)

[1]Total surface water area receiving more than 10 kilograms per hectare per year of sulphate deposition.
[2]Sensitivity is based on potential of surrounding soils and bedrock to reduce acidity.
[3]No data available for Newfoundland and Labrador.
[4]Totals may not add due to rounding.
Source: United States–Canada Memorandum of Intent on Transboundary Air Pollution, Work Group 1, *Final Report*, January 1983.

Table 8.12
Agricultural Crop Areas in Eastern Canada, by Crop and Deposition, 1976

	Sulphate Deposition (kg/ha/yr)	Area (thousands of hectares)							
		Wheat	Oats	Barley	Corn[1]	Soybeans	Potatoes	Tobacco	Hay
Ontario	10-20	0.2	8.2	2.4	0.1		0.5		40.1
	20-40	52.7	106.3	39.8	236.8	1.7	4.0	13.4	532.0
	>40	159.9	92.5	105.0	774.3	149.4	14.0	20.8	520.6
Quebec	10-20	0.6	9.5	1.4	0.1		0.2		50.0
	20-40	25.7	183.5	11.9	130.8	0.2	11.2	3.8	595.2
	>40	5.1	102.0	4.8	33.4		4.9		405.8
Atlantic[2]	10-20								
	20-40	10.3	56.0	15.1	11.6		45.3	1.9	198.2
	>40								
Overall	10-20	0.8	17.7	3.8	0.1		0.6		90.1
	20-40	88.7	339.8	66.9	381.3	1.9	60.5	19.0	1 325.5
	>40	165.0	194.5	109.8	807.7	149.4	18.9	20.8	926.4
Total[3]		254.5	552.0	180.5	1 189.1	151.3	80.0	39.8	2 342.0

[1]Corn includes both grain corn and fodder corn.
[2]Some of the Atlantic area data are based on other years — 1979, 1980 or 1981.
[3]Figures may not add due to rounding.
Source: United States–Canada Memorandum of Intent on Transboundary Air Pollution, Work Group 1, *Final Report*, January 1983.

several area studies indicating the seriousness of the problem.

The most frequently quoted case study, of lakes in the Lac Cloche Mountains area near Sudbury, Ontario, demonstrated the loss of fish species and the vulnerability of 30 fish species to acidification. A general rule of thumb that emerges, although it is subject to geographic variation, is that below a pH of 5.5 lakes are more frequently devoid of fish. Data for 57 headwater streams in the Muskoka-Haliburton region of Ontario show that 65 per cent experience minimum pH values less than 5.5, and 26 per cent have minimum pH values of less than 4.5.

Recently in Ontario, an acid stress/lake sensitivity procedure was used to evaluate 6 300 lakes on the basis of the presence or absence of 20 key sportfish species. Over 300 000 hectares of approximately 11 400 lakes were considered to be at moderate to high risk, representing a potential loss of 30 per cent or more of the total provincial resource of at least 5 major fish communities. Most vulnerable were brook trout, lake trout and bass.

Similar documentation is not available for the rest of eastern Canada. However, the spawning and nursery areas of east coast rivers and streams important to Atlantic salmon should be considered particularly vulnerable. Most Atlantic salmon spawning streams and rivers occur in areas of high sulphate deposition. In Nova Scotia, 9 of 27 salmon-producing rivers (representing 30 per cent of the total) with a pH less than 4.7 had lost historical reproducing populations of salmon and trout.

A summary of crop areas for selected agricultural crops in eastern Canada, cross-classified by sulphate deposition, appears in Table 8.12. It is evident that very large proportions of the specified crops are grown in areas of moderate to high sulphate deposition (greater than 20 kg/ha/y). To date, no definitive cause-effect relationship has been found with respect to these sulphate deposition levels and specific crop reductions. Further work is required to determine individual crop sensitivities to sulphate deposition levels. For example, alkaline soils might be improved by some acidification for some time before showing signs of deterioration. Direct effects on crop productivity may be less important than indirect effects such as the increased mobility of metals like aluminum. Certainly the fact remains that the bulk of the agricultural crops in eastern Canada are exposed to relatively high sulphate deposition rates.

Damage to trees downwind from high-level point-sources of SO_2 emissions has been well documented (see Chapter 4). Local damage is, for the most part, caused by the direct effect of atmospheric concentrations of SO_2 and associated particulates.

Studies have shown that acid rain can affect forests directly by acting on the foliage or indirectly by changing the properties of the soil supporting forest growth. Sensitivity varies with species and the buffering capacity of soils. Coniferous forest soils are believed to be especially vulnerable. Forest growth is a slow process, and the effects of gradually increasing accumulations of acidic deposition need long-term studies in the context of different background variables, physiological processes, and regional climate factors.*

Table 8.13 provides a summary of forest area and annual growth by forest type in eastern Canada, cross-classified by sulphate deposition. The data indicate that in eastern Canada approximately 40 per cent of the area and 45 per cent of the annual yield occurs in those parts where sulphate deposition exceeds 20 kg/ha/y. Comparing forest types, nearly 75 per cent of the annual hardwood yield occurs in the area where deposition is greater than 20 kg/ha/y, whereas only 30 per cent of the annual softwood yield occurs in areas subject to greater than 20 kg/ha/y of sulphate deposition.

In February 1985, the environment ministers of seven provinces (Manitoba to Newfoundland) and the federal Minister of the Environment reached an agreement concerning the sharing of specific reductions in annual SO_2 emissions to arrive at a 1994 figure of 2.6 million tonnes. This is an upper limit, and it was agreed to reduce levels to 2.3 million tonnes if feasible (representing 50 per cent of the 1980 base case). These reductions are expected to achieve a target level of 20 kg/ha/y. Given that much of the source of acid rain is in United States (see Table 8.10), these targets also serve as standards for bilateral agreements.

The acid rain issue is not limited to North America, and efforts have been made to reach international agreement on specific emission reduction targets. The Economic Commission for Europe Convention on Long-Range Transboundary Air Pollution provides a framework for developing a concerted international effort to reduce acid rain. Both Canada and the United States have signed this convention. In March 1984 several nations undertook to reduce national sulphur emissions by at least 30 per cent by 1993 at the latest.** The agreement also included reductions of nitrogen oxide emissions from stationary and mobile sources.

SELECTED PESTICIDES

Pesticides are unique in that, unlike many other chemicals that find their way into the environment through waste handling or leakage from industrial processes, they are intended for widespread use. As a by-product

*One regional factor to have emerged quite recently is the phenomenon of 'acid fog', observed in mountainous and coastal regions. Poor natural buffering makes this a special concern in the Atlantic Maritime ecozone. In addition, parts of the heavy snowfall zone of the coastal mountains (Pacific Maritime ecozone) experience 'acid shock' during spring runoff, because of the accumulation of acid snow over the winter.

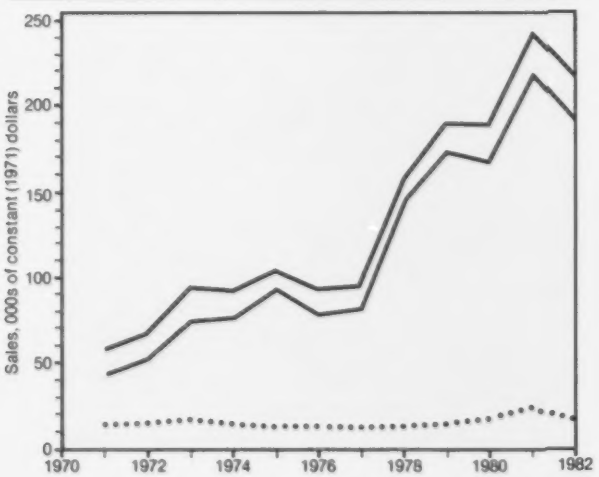
**The following countries met in Ottawa in March 1984 and agreed to these targets: Canada, Austria, Denmark, the Federal Republic of Germany, Finland, France, the Netherlands, Norway, Sweden and Switzerland.

Table 8.13
Forest Area and Annual Growth in Eastern Canada, by Forest Type[1] and Deposition

	Sulphate Deposition (kg/ha/y)	Forest Area (000s ha)	Annual Yield[2] (thousands of cubic metres)			Total Annual Yield (000s m^3)
			Softwood	Mixed-Wood	Hardwood	
Ontario	10-20	18 600	26 219	124	4 722	31 065
	20-40	7 095	4 855	2 007	5 682	12 544
	> 40	444	425		573	998
Quebec	10-20	34 061	39 074	7 957	332	47 363
	20-40	15 998	10 648	15 423	3 589	29 660
	> 40	2 048	426	2 760	1 252	4 438
Atlantic	10-20	2 570	1 460	246	28	1 734
	20-40	13 253	11 311	7 911	3 220	22 442
	> 40					
Overall	10-20	55 231	66 753	8 327	5 082	80 162
	20-40	36 346	26 814	25 341	12 491	64 646
	> 40	2 492	851	2 760	1 825	5 436
Total		94 069	94 418	36 428	19 398	150 244

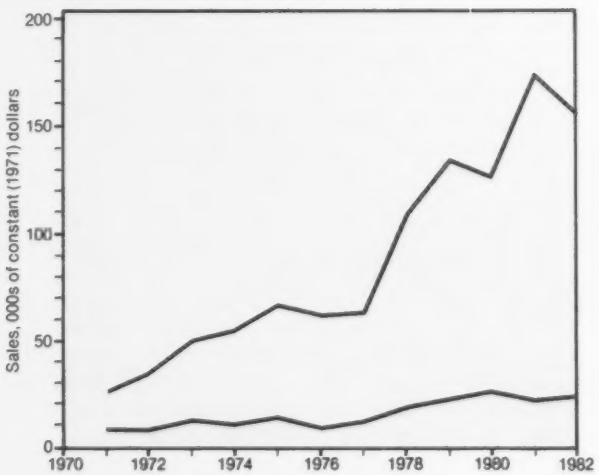
[1]Hardwood and softwood forests contain 70 per cent or more of the specified type; mixed-wood forests contain less than 70 per cent of either type.
[2]Annual yield does not include data on regions receiving less than 10 kg/ha/y sulphate deposition.
Source: United States–Canada Memorandum of Intent on Transboundary Air Pollution, Work Group 1, *Final Report*, January 1983.

Figure 8.4
Sale of Pesticides for Agricultural and Home and Garden Use, 1971-1982



[1] Total sales include sales for other industrial uses.
Source: 1971-77: Statistics Canada, *Sales of Pest Control Products by Canadian Registrants*, Catalogue 46-212.
1978-1982: Canadian Agricultural Chemicals Association.
Miscellaneous Chemical Industry Pest Control Product Selling Price Index: Statistics Canada, *Industry Price Indexes*, Catalogue 62-011.

Figure 8.5
Sale of Pesticides for Agricultural Use in Canada, 1971-1982



Source: 1971-77: Statistics Canada, *Sales of Pest Control Products*, Catalogue 46-212.
1978-1982: Canadian Agricultural Chemicals Association.

Table 8.14
Quantities of Active Ingredients of Pesticides used in the Ontario Part of the Great Lakes Drainage Basin, 1973 and 1978
(kilograms)

Drainage Basin[1]	Quantities of Active Ingredients of Pesticides Used in Field Crops							
	1973				1978			
	Herbicides	Insecticides	Fungicides	Total	Herbicides	Insecticides[2]	Fungicides	Total
Lake Huron & Georgian Bay	406 000	19 350	425	425 775	715 250	26 470	1 090	742 810
Lake St. Clair	515 160	226 520	240	741 920	1 114 270	310 340	2 070	1 426 680
Lake Erie	466 840	1 160 030	3 570	1 630 440	687 680	980 050	860	1 668 590
Lake Ontario	225 030	18 380	70	243 480	405 120	25 320	460	430 900
Total	1 613 030	1 424 280	4 305	3 041 615	2 922 320	1 342 180	4 480	4 268 980

Drainage Basin[1]	Quantities Used on Field Crops, Fruits, Vegetables & Roadsides			
	1978			
	Herbicides	Insecticides[2]	Fungicides	Total
Lake Huron & Georgian Bay	1 014 590	94 400	91 580	1 200 570
Lake St. Clair	1 217 130	327 390	26 320	1 570 840
Lake Erie	1 094 540	1 347 270	91 740	2 533 550
Lake Ontario	683 410	203 920	157 640	1 044 970
Total	4 009 670	1 972 980	367 280	6 349 930

[1]For the field crop comparisons, the drainage basins defined in the 1978 report were used except for the elimination of lakeside land from each basin. For the field crops, fruit, vegetables and roadsides summary, all areas were included as shown in the 1978 report.

[2]For 1978, Insecticides is an aggregate of insecticides, nematocides and growth regulators.

For all Ontario in 1978, 5 herbicides accounted for 75 per cent of the herbicides used, 7 insecticides accounted for 50 per cent of the insecticides used, and 1 nematocide accounted for 60 per cent of the nematocides, fungicides and growth regulators.

Source: Ontario Ministry of Agriculture and Food, *Survey of Pesticide Use in Ontario 1973* and *Survey of Pesticide Use in Ontario 1978*.

Table 8.15
Active Ingredients of Pesticides used for Aerial Application in New Brunswick, 1981-83
(kilograms)

	Insecticides[1]	Herbicides	Fungicides	Total
1981	733 925	5 561	59 180	798 666
1982	673 300	30 017	56 277	759 594
1983	886 258	50 074	61 707	998 039

[1]Fenitrothion accounts for about 95 per cent of the insecticides applied aerially each year.

Source: Environment New Brunswick, *Pesticide Usage in New Brunswick, 1981, 1982, 1983*.

of their intended use, pesticides or their derivatives may find their way into other parts of the environment by leaching into groundwater systems, runoff into surface waters, or incorporation into food products and drinking water. Some of these compounds are readily biodegradable and are assimilated into the environment with very little long-lasting effect. Some, however, are much more persistent and can be highly mobile, being transported significant distances from the point of application. Other compounds may interact in different ways with various chemicals, giving a combined effect considerably different from that expected of either chemical alone.

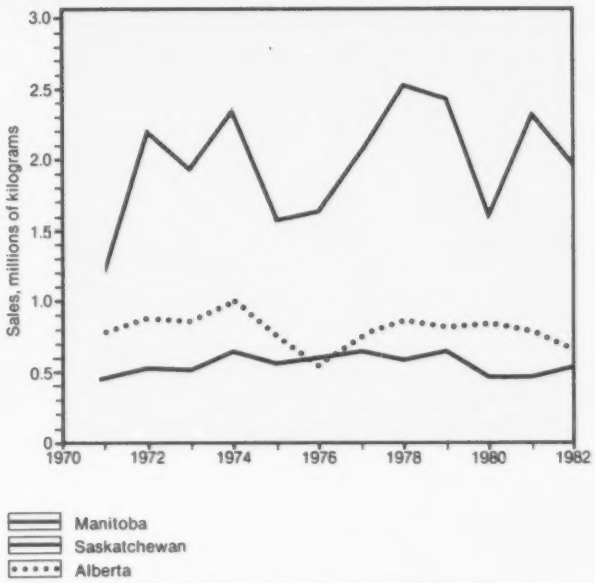
As knowledge and understanding of these various kinds of effects increase, more attention is being placed on developing integrated pest management control programs. These programs make use of a combination of chemical (pesticide) and biological control methods to produce the most effective results with the minimum application of chemicals. This is an important area for continuing research, because it appears that, in some cases at least, strains of various pests evolve that are more resistant to previously effective chemical treatment.

Nevertheless, chemical pesticide use has increased dramatically during recent years. For example, Figure 8.4 shows the annual sales of pesticides for agriculture and for home and garden use since 1971. The data are expressed in constant 1971 dollars using Statistics Canada's pest control products price index to convert figures published in current dollars. Overall, there has been about a four-fold increase, but it is clear that agricultural use predominates. The breakdown of sales of agricultural insecticides and herbicides is shown in Figure 8.5. The rapidly increasing usage of herbicides can be seen clearly; in 1971, herbicide sales values were three times those of insecticides, whereas by 1981-82, relative sales were running at about eight to one. These data reflect a change in agricultural weed control from mechanical to chemical methods.

Data concerning the quantities of specific pesticides used are more difficult to obtain. The wide range of products and formulations available also make it difficult to select a representative sample. More detailed information is, however, available from various provincial agencies.

Table 8.14 provides a comparison of quantities of the active ingredients in pesticides used in the Ontario part of the Great Lakes drainage basin. Figures show quantity applied to field crops for the years 1973 and 1978. The 1978 survey had a wider coverage and, in addition to field crops, included fruit, vegetable and roadside spraying. (Substantial quantities are used for the latter purposes.) During the period surveyed, the data show substantial increases in the use of both herbicides and insecticides for field crops in all drainage basins, except for insecticide use in the Lake Erie basin. Southwestern Ontario is the area of most intensive application of agricultural chemicals

Figure 8.6
2,4-D Sold in the Prairie Provinces, 1971-1982



Source: Manitoba Department of Agriculture, *Herbicides Used Agriculturally in Western Canada for Weed Control*, Annual figures.

in Canada. However, the area of concentration becomes even more striking when one considers that 90 per cent of the insecticides and 60 per cent of the herbicides applied to field crops in 1973 and 1978 were in the Lake Erie-Lake St. Clair basin. This basin is smaller than the Lake Ontario basin and about one-third the size of the Lake Huron and Georgian Bay basin.

Table 8.15 shows the active ingredients of pesticides used in aerial spraying in New Brunswick. Insecticides applied aerially (largely fenitrothion) are used to combat spruce budworm and are subject to a permit control procedure that takes into account the extent of the infestation each year. Herbicides and fungicides, accounting for about 10 per cent of aerial spraying, are applied largely to potato crops. In the three-year period between 1981 and 1983, about 2.6 million kilograms of pesticides were sprayed aerially over large tracts of the province of New Brunswick, mostly over forestland. Although the data are insufficient to obtain a picture of trends, the amount of aerially applied pesticides was nevertheless about 200 000 kilograms more in 1983 than in 1981.

Data from 1971 to 1982 on the use of the herbicide 2,4-D in the three prairie provinces have been plotted in Figure 8.6. The data show sizable year-to-year fluctuations in each province, with no clear trend emerging over time. Substantially more 2,4-D is used in Saskatchewan, with Alberta and Manitoba following. The use of 2,4-D in the prairie provinces is much more extensive than in other parts of Canada.

Table 8.16
NAQUADAT Water Quality Data — 2,4-D[1]

Drainage Basin	1971-73			1974-76			1977-79			1980-82		
	Number of Samples	% of samples >0.5 µg/L	% of samples >1.0 µg/L	Number of Samples	% of samples >0.5 µg/L	% of samples >1.0 µg/L	Number of Samples	% of samples >0.5 µg/L	% of samples >1.0 µg/L	Number of Samples	% of samples >0.5 µg/L	% of samples >1.0 µg/L
1 Atlantic Coast 2 Gulf of St. Lawrence 3 Bay of Fundy 4 St. Lawrence River 5 Ottawa River 6 Lake Ontario 7 Lake Erie/St. Clair 8 Lake Huron 9 Lake Superior												
10 Hudson Bay	14	0	0	39	0	0	67	0	0	78	0	0
11 Nelson River	—			—			—			—		
12 Lake Winnipeg	32	3.1	0	77	0	0	160	4.4	3.8	183	0	0
13 Assiniboine River	295	8.5	3.4	304	1.3	0.7	155	3.9	1.3	140	0	0
14 Saskatchewan River	288	0	0	442	0	0	381	1.8	0.5	378	0.3	0
15 Mackenzie River	106	0	0	149	0	0	66	0	0	90	0	0
16 Arctic Ocean 17 Columbia River 18 Fraser River 19 Yukon River 20 Pacific North Coast 21 Pacific South Coast												
22 Milk River	6	0	0	31	0	0	77	0	0	85	0	0
Total	743	3.5	1.3	1 042	0.4	0.2	906	2.2	1.1	954	0.1	0

[1]Data from NAQWEST only.
[2]NAQUADAT parameter code for 18500 was used to prepare this table.
[3]Herbicide formulation industries are located near Regina and Winnipeg (Water Basins 12 and 13).
Source: Environment Canada, NAQWEST portion of NAQUADAT database.

The data from the NAQUADAT water quality datafile in the western region (NAQWEST) were searched to determine the presence of 2,4-D in surface water samples from the western region water basins. The total number of samples analyzed and the number of analyses that exceeded either 0.5 micrograms (10^{-6} g) or 1 microgram per litre (µg/L) were recorded for each water basin for each of four three-year periods.* Concentrations in excess of 1 µg/L may be detrimental to the aquatic invertebrate community. The results of this search are summarized in Table 8.16 and mapped in Figure 8.7. The total number of samples in each period ranged from 743 to 1 042. Two of the drainage basins where some samples exceeded the specified limits happen to include herbicide manufacturers, but these industries were not specifically pinpointed as the source. From these data there is no evidence that 2,4-D is causing widespread contamination of river basins.

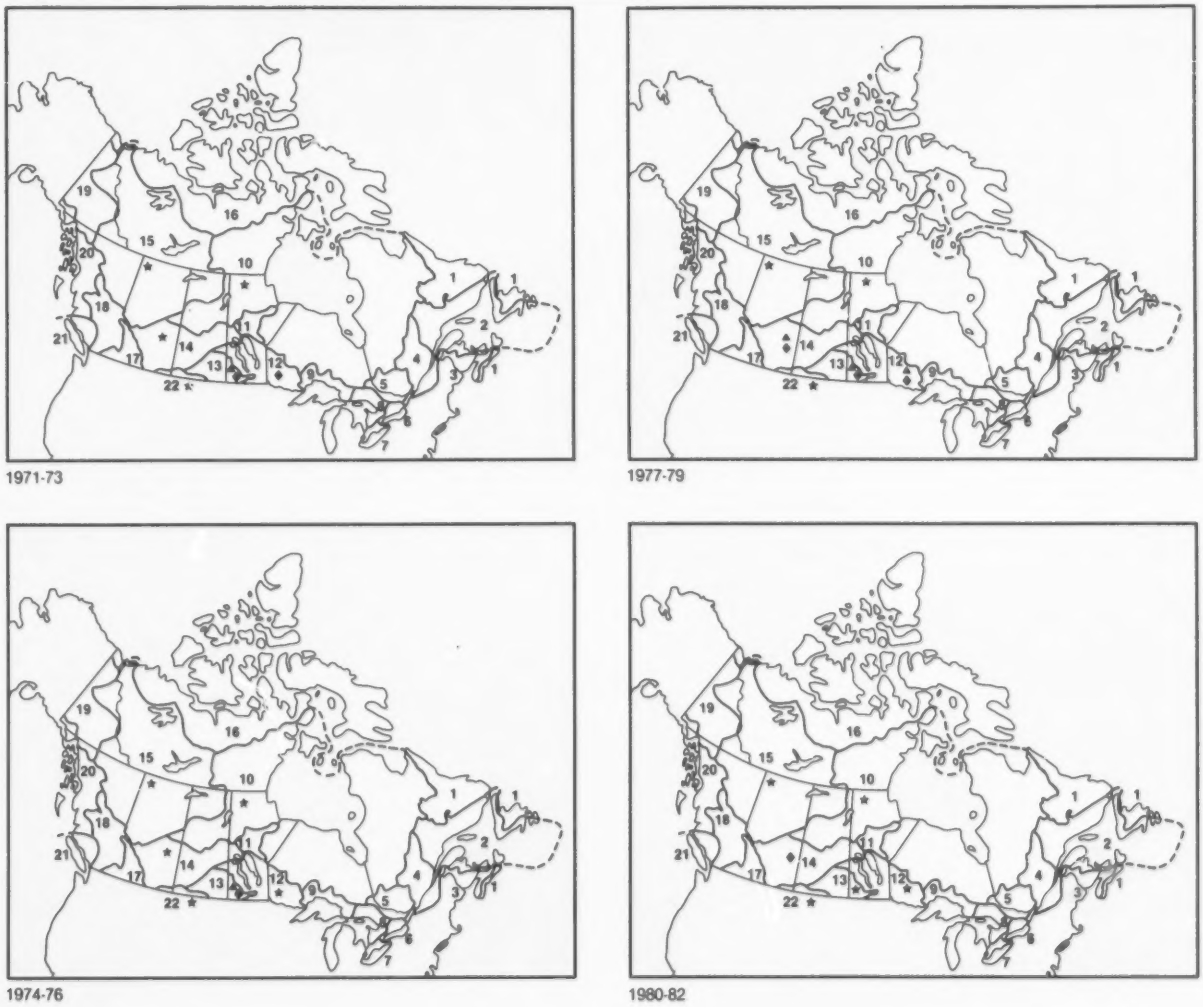
Because a number of other specific pesticides may cause concern, the NAQWEST datafile was also searched to determine whether any relevant information was available. No data were recorded for pentachlorophenol, fenitrothion, aminocarb or atrazine. Although entries were recorded for dieldrin, endrin and chlordane, 99.5 per cent of the records indicated levels below the detection limit. Some data reported detectable levels of aldrin, DDT, lindane, methoxychlor and 2,4,5-T, but values were so much below published guidelines that further examination of the NAQUADAT file did not seem warranted.

This should not be interpreted as a dismissal of the possible long-term significance of such compounds. Many pesticides are insoluble or only slightly soluble in water; they therefore tend to accumulate in bottom sediments. Such sediments serve as a reservoir from which these compounds or their derivatives may move back into the biological web, posing a long-term threat to aquatic species and the environment generally.

Some of these pesticides are known to be highly persistent, mobile and bio-accumulative and have already been associated with adverse ecological or human health effects. Data from various other monitoring programs were reviewed, therefore, to determine whether compounds such as DDT (or its

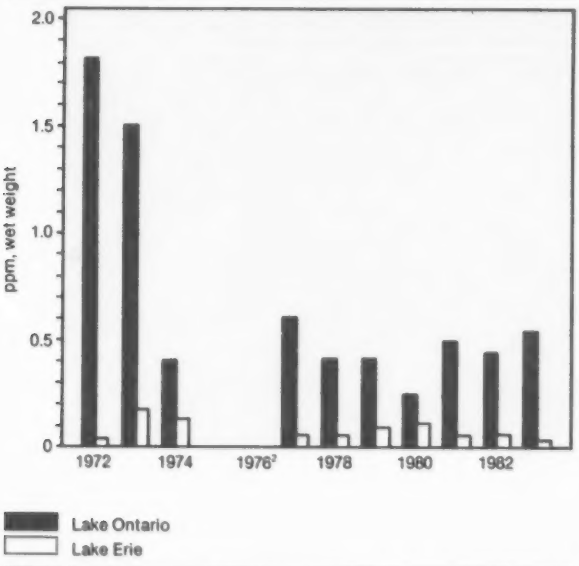
*Canadian drinking water objectives for 2,4-D are maximum acceptable, 100 µg/L; desirable objective, 1 µg/L.

Figure 8.7
2,4-D in Major Drainage Basins of Western Canada


1971-73
1977-79
1974-76
1980-82
▲ > 1.0 µg/L in < 10% of samples
♦ > 0.5 µg/L in < 10% of samples
★ < 0.5 µg/L in all samples
Minimum of 6 samples per drainage basin
770 0 770 1540 kilometres

Source: Environment Canada, NAQWEST portion of NAQUADAT Database.

Figure 8.8
Σ DDT in Smelt, Lake Ontario and Lake Erie, 1972-1983[1]



[1] Data for 1972-77: edible portion; data for 1977-1983: whole fish.
[2] No data collected in 1975 and 1976.
Source: Great Lakes Water Quality Board, *Great Lakes Water Quality*. Reports to the International Joint Commission, 1981, 1985.

Figure 8.9
Selected Nesting Colony Sites for Herring Gull Egg Sampling Program

1 Middle Island
2 Port Colborne
3 Scotch Bonnet Island
4 Snake Island

metabolite, DDE), dieldrin and the dioxin 2,3,7,8-TCDD have been found.

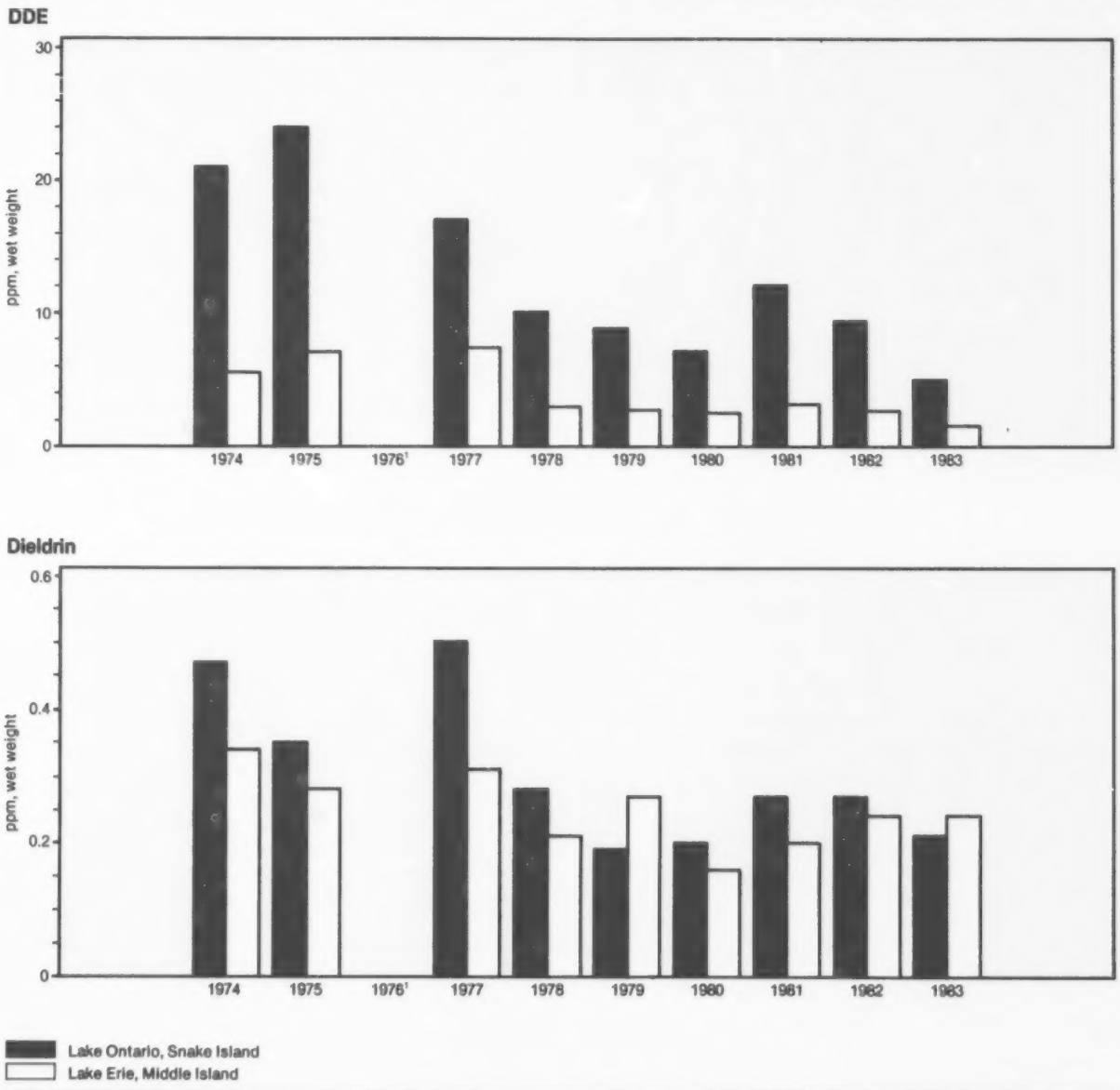
The Great Lakes are one of the most environmentally monitored areas in Canada. The 1972 and 1978 Great Lakes Water Quality Agreements called for specific actions by both countries consistent with the intent of the 1909 Boundary Waters Treaty. A wide variety of monitoring programs has been undertaken to assess the nature and extent of contamination of the whole Great Lakes ecosystem.

The changing levels of ΣDDT (total DDT and metabolites) in smelt from Lake Ontario and Lake Erie (1972-1983) are shown in Figure 8.8. Levels in Lake Ontario smelt were significantly higher than levels in smelt taken from Lake Erie. Widespread use of DDT in Canada was banned in 1972, and Lake Ontario levels have decreased; since 1977 there have been year-to-year fluctuations and no obvious trend.[3] The data for Lake Erie do not, however, suggest any consistent pattern. These surveys were conducted primarily as spot checks and not for trend analysis.

Herring gull eggs have been found to be one of the most useful indicators for a variety of contaminants. They represent another level higher than fish in the food chain. Samples of herring gull eggs taken from the same area year after year are particularly useful in trend analyses. Figure 8.9 is a map of the Great Lakes showing several herring gull egg sampling sites. Data for DDE levels in herring gull eggs[5] taken regularly from Middle Island in Lake Erie and Snake Island in Lake Ontario are shown in Figure 8.10. These data are consistent with the smelt data; they show that levels in Lake Ontario are somewhat higher than in Lake Erie and that, overall, there was a downward trend between 1974 and 1983. Data for 1978-1982 may indicate a levelling off, but the 1983 results suggest a continuing decline. The herring gull eggs were also assayed for dieldrin, an insecticide registered for commercial use for mite control. The results are shown in Figure 8.10. (Another insecticide, aldrin, may be slowly converted to dieldrin.) There is little difference between dieldrin levels in the two lakes, and the data suggest a recent levelling off.

The compound 2,3,7,8-TCDD is considered one of the most toxic of the large number of dioxins that exist. It has been identified as a contaminant in the

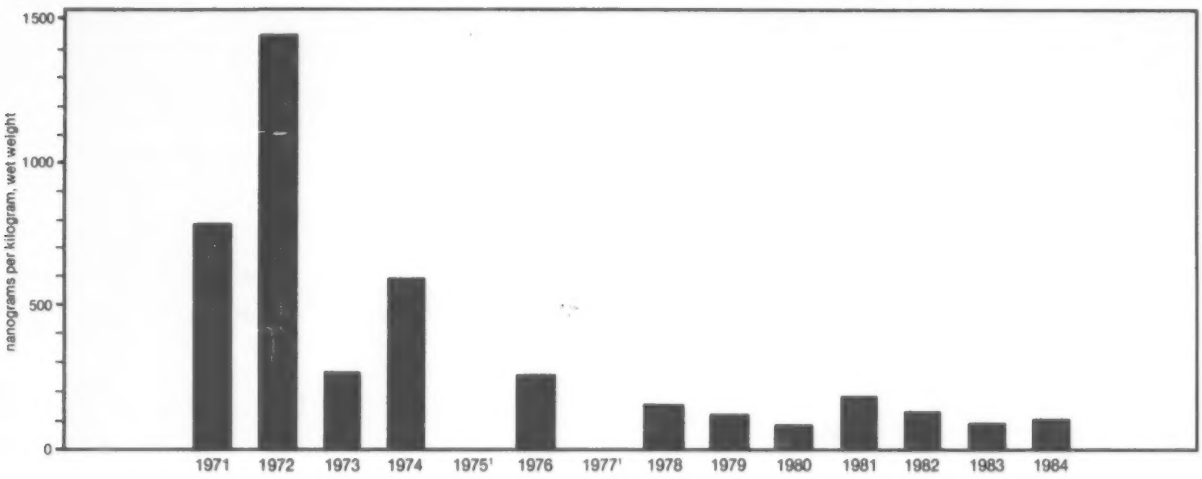
Figure 8.10
DDE and Dieldrin in Herring Gull Eggs from Lake Ontario and Lake Erie, 1974-1983



[1] No data collected in 1976.

Source: 1974-77: D.V. Weseloh et al., "Organochlorine contaminants and trends in reproduction in Great Lakes Herring Gulls, 1974-78", Transactions of 44th North American Wildlife and Natural Resources Conference, 1979.
1978-1982: Personal Communication, D.V. Weseloh, Canadian Wildlife Service, Ontario Region, Environment Canada, 1985.

Figure 8.11
2,3,7,8-TCDD in Herring Gull Eggs from Scotch Bonnet Island, Lake Ontario, 1971-1984



¹ No data collected in 1975 and 1977.
Source: Personal communication, R.J. Norstrom, Canadian Wildlife Service, Environment Canada, 1985.

herbicide 2,4,5-T and as a by-product of combustion. Measurements of this compound have been made in herring gull eggs taken from Scotch Bonnet Island in eastern Lake Ontario since the early 1970s. Figure 8.11 depicts data from 1971 to 1984. Trends show a sharp decline in the early 1970s with a levelling off from the late 1970s onward. In 1984, levels in eastern Lake Ontario were about twice as high as those in western Lake Ontario.

Levels of DDT and dieldrin in tobacco soils in Ontario have been sampled sporadically since 1970 (see Figure 8.12). Usually the sample involved more than 30 farms, although the fields tested were not always the same. There seems to be little doubt about the persistence of both compounds in soil and the fact that decreases are occuring very slowly, if at all, in the case of dieldrin.[2]

Measurements of DDE and dieldrin have been made in the eggs of Leach's petrel, the Atlantic puffin and the double-crested cormorant collected from specific sites along the Atlantic coast. These sites are shown in Figure 8.13, and the results of the measurements are given in Figure 8.14. Leach's petrel is a pelagic (oceanic) species that feeds on surface microorganisms of the open ocean; the Atlantic puffin is a pelagic species that feeds on fish; and the double-crested cormorant is a coastal species that feeds largely on fish. Data for the four periods (1972, 1976, 1980 and 1984) indicate significant decreases in the DDE levels in all species and at all sites, except for the double-crested cormorants at Île-aux-Pommes, where the 1984 data indicate an increase. DDE levels observed in samples taken off the coast of Newfoundland and in the Gulf of St. Lawrence seem to be less than levels in samples from the Bay of Fundy. In the case of dieldrin, trends are more difficult to identify, although the data for the eggs of the double-crested cormorant colony in Manawagonish, New Brunswick seem to suggest a downward trend.

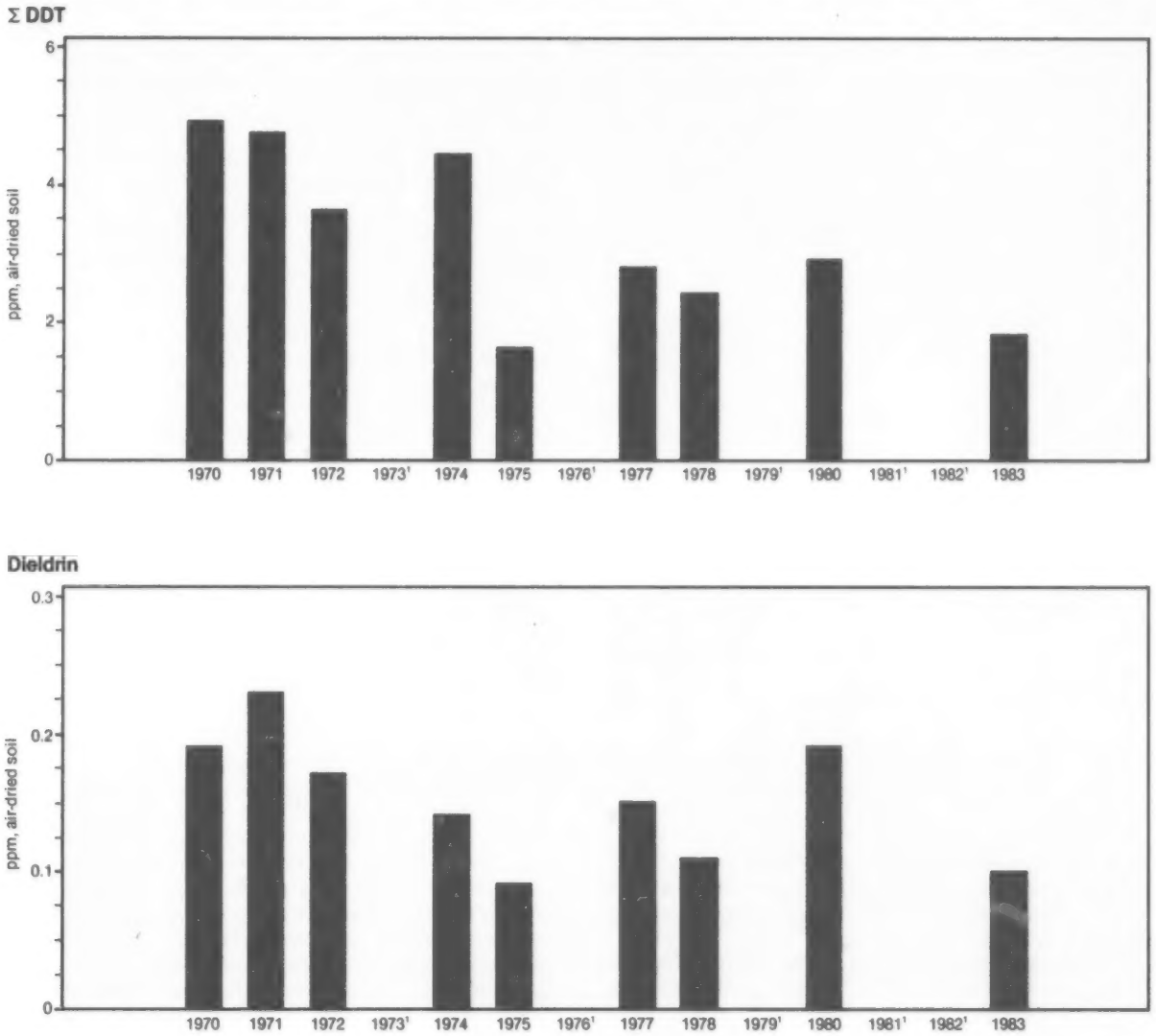
SELECTED INDUSTRIAL ORGANIC COMPOUNDS

Two of the many industrial organic compounds that have been monitored extensively are the polychlorinated biphenyl group (PCBs) and mirex. PCBs are used in plasticizers, hydraulic fluids, lubricants and sealers and as dielectric fluid in transformers. They are highly resistant to biological, chemical and thermal degradation, relatively insoluble in water, and accumulate in the food chain and in fatty tissues of animals. Their use has been restricted and subject to control since 1977.

Mirex has been used extensively as a fire retardant and has been found widely throughout the environment. It has many of the same chemical and biological properties as PCBs. Although mirex has never been manufactured in Canada and has not been imported since 1969, its use has been subject to control since 1978.

The combination of previous widespread use and the chemical and biological properties of these compounds make it worthwhile to review available monitoring data. As stated earlier, the NAQWEST database did not produce useful information relating to PCBs or mirex in river basin monitoring. Data are available, however, for PCB concentrations in smelt found in Lake Ontario and Lake Erie. In addition, data

Figure 8.12
Levels of ΣDDT and Dieldrin in Tobacco Soils, Ontario, 1970-1983



[1] No data collected.

Source: 1970-75: R. Frank et al., "Metal contents and insecticide residues in tobacco soils and cured tobacco leaves collected in Southern Ontario", *Tobacco Science* XXI (1977): 74-80.
1977-78: R. Frank et al., "Insecticide residues and metal contents in flue-cured tobacco and tobacco soil of Southern Ontario. 1976-78", *Tobacco Science* XXIV (1980); 136-140.
1980-83: Personal Communication, R. Frank, Ontario Ministry of Agriculture and Food, Guelph, 1984.

Figure 8.13
Selected Atlantic Coast Nesting Colonies For Bird Egg Sampling Program

1 Île-aux-Pommes, Quebec
2 Great Island, Newfoundland
3 Manawagonish Island, New Brunswick
4 Kent Island, New Brunswick
5 Machias Seal Island, New Brunswick

from the egg sampling program conducted by the Canadian Wildlife Service in the Great Lakes include PCBs and mirex, and the Atlantic coast egg sampling program includes data on PCBs.

The results of spot check measurements for PCBs in smelt from Lake Ontario and Lake Erie between 1972 and 1983 are shown in Figure 8.15. Lake Ontario levels are considerably higher than those in Lake Erie and, although there has been a decrease since the first reports, levels do not seem to have changed much recently.

The changing pattern of PCB and mirex levels in herring gull eggs collected at three sites in Lake Erie and Lake Ontario between 1974 and 1983 is shown in Figure 8.16. Concentrations of PCBs are almost 100 times greater than those of mirex, especially in Lake Erie. Mirex levels in the samples taken from Lake Ontario are 10 to 20 times higher than levels in the Lake Erie samples. Concentrations of both PCBs and mirex in samples from all three sites decreased between 1974 and 1978. Between 1979 and 1982, the levels varied, with some indication that they might, in fact, be increasing again. The 1983 results for both contaminants at all sites showed marked decreases compared with 1982 results.

Figure 8.17 shows the PCB results for the three Atlantic coast species (Leach's petrel, Atlantic puffin and double-crested cormorant) for 1972, 1976, 1980 and 1984. The data for Leach's petrel seem to indicate that PCB levels are decreasing, but much more slowly than DDE levels (Figure 8.14). Concentrations in Atlantic puffin egg samples taken from the Bay of Fundy were considerably higher than levels in samples from Newfoundland. The PCB levels from the Bay of Fundy samples show a declining trend, but the Newfoundland data show a steady increase in PCB levels until 1980 and then a sharp decrease in 1984. The data for the double-crested cormorant eggs are so variable that they do not allow generalization about trends or differences between the two sampling sites. Overall, PCB concentrations in the eggs of double-crested cormorants seem to be higher than in the eggs of the other two species. It should be noted that contaminant levels in these samples are considerably lower than those found in the Great Lakes.

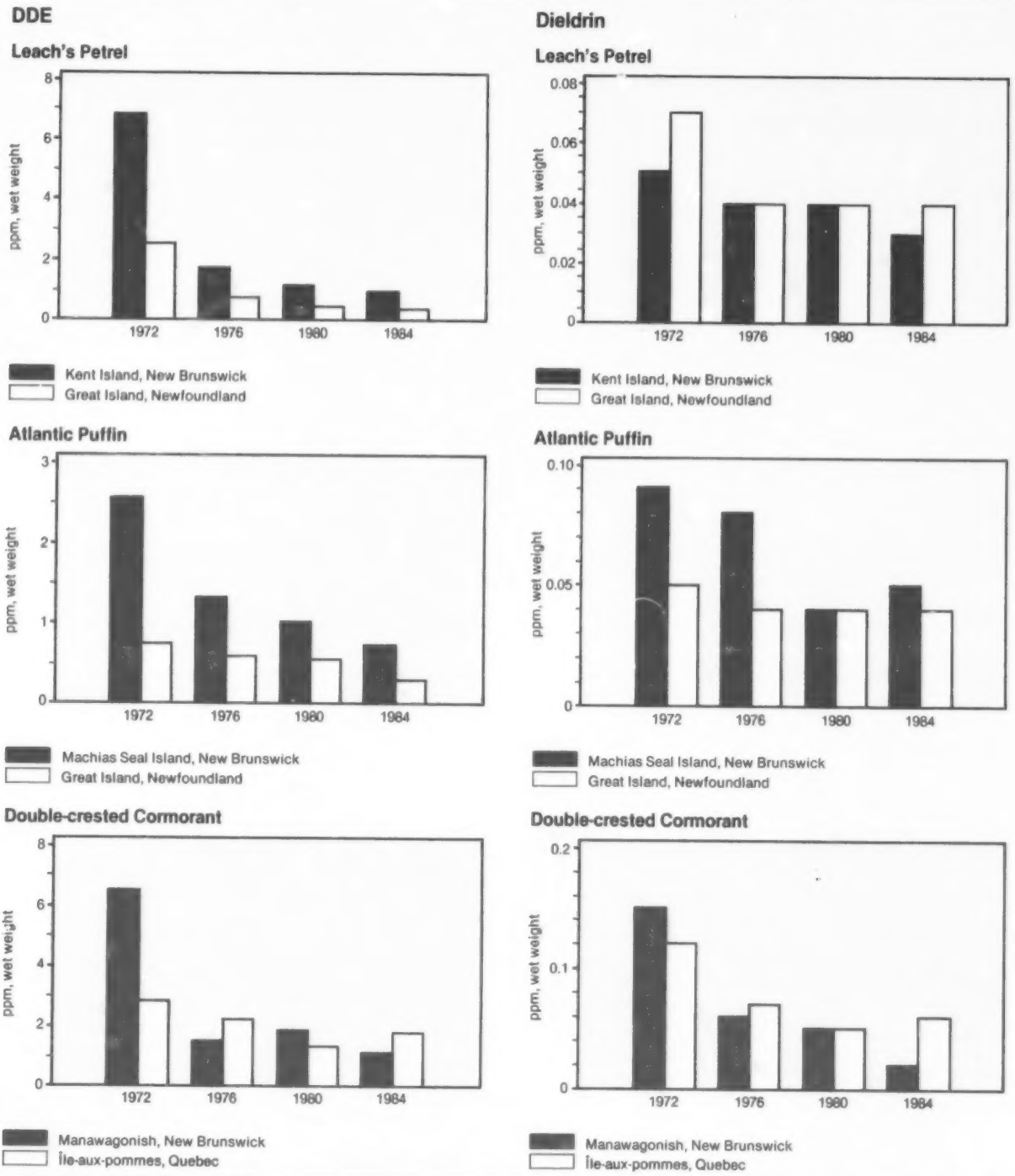
HAZARDOUS WASTES AND SELECTED INORGANIC SUBSTANCES

Public health authorities have long been concerned about the relationship between disease and the management and treatment of municipal wastes — both wastewater and refuse or garbage. For many years, the most common practice was to dispose of refuse in sanitary landfills. Although quantitative data have not been systematically collected in Canada, it has been estimated that the average daily generation of waste amounts to between one and three kilograms per person. On the basis of two kilos per person per day, this amounts to more than 18 million tonnes per year in Canada. As populations and urban areas grow, satisfactory landfill sites are becoming more difficult to find. Concern is expressed not only about the availability of adequate space and the costs involved, but also about the health risks associated with the disposal of hazardous substances and their subsequent seepage or release into the environment. Some of these same health concerns are also expressed about the disposal of hazardous wastes by incineration.

The handling and disposal of toxic or hazardous chemicals, from the moment of their manufacture to their ultimate disposal, has become an environmental issue of major concern to Canadians. For many, the most alarming aspect is the long-term consequences of unregulated or unsatisfactory disposal methods, which could lead to serious health or ecological problems in the future. Public concern about potential exposure has made it difficult for authorities to obtain support for any particular site for managed disposal of hazardous wastes. Although people recognize the need for sites, they typically adopt a 'not-in-my-backyard' attitude.

The full extent of the hazardous wastes disposal

Figure 8.14
Levels of DDE and Dieldrin in Eggs of Atlantic Coast Bird Species



Source: 1972, 1976: Peter A. Pearce et al., *Pesticides Monitoring Journal* 13/2 (1979): 61-68.
1980, 1984: Personal Communication, D.B. Peakall, Canadian Wildlife Service, Environment Canada, 1984, 1985.

Table 8.17
Hazardous Waste Generation[1] in Canada by Waste Type, 1982
(tonnes)

Condolidated Waste Type	British Columbia	Alberta	Saskatchewan	Manitoba	Ontario	Quebec
Organic Sludges and Still Bottoms (No Oil)	500	900	300	200	35 000	22 200
Solvents and Organic Solutions	4 100	6 700	3 200	2 900	39 800	166 700
Oils and Greases	21 000	20 300	14 200	10 200	48 200	109 800
Oil/Water Mixtures	1 400	1 700	900	700	54 300	16 900
Organic and Oily Residuals	1 100	1 300	400	600	209 100	3 600
Heavy Metal Solutions and Residuals	22 400	31 600	13 400	2 650	545 900	467 100
Miscellaneous Chemicals and Products	3 700	9 200	600	300	142 000	41 800
Paint and Organic Residuals	400	700	200	200	49 000	15 600
Aqueous Solutions with Organics	5 600	7 900	4 200	11 200	700	21 900
Anion Complexes	200	490	100	340	33 500	5 700
Sludges and Inorganic Residuals	2 900	3 500	4 400	2 200	242 000	74 600
Pesticide and Herbicide Wastes	90	200	100	NA	600	2 700
PCB Wastes	10	10	NA	10	200	NA
Clean-Up Residuals	2 900	3 000	200	1 800	7 500	3 300
Total	66 300	87 500	42 200	33 300	1 407 800	951 900

Condolidated Waste Type	New Brunswick	Nova Scotia	Prince Edward Island	Newfoundland	Total
Organic Sludges and Still Bottoms (No Oil)	500	2 300	10	800	62 710
Solvents and Organic Solutions	7 800	10 200	75	5 200	246 675
Oils and Greases	18 600	13 900	100	700	257 000
Oil/Water Mixtures	100	2 100	10	30	78 140
Organic and Oily Residuals	50	100	1	50	216 300
Heavy Metal Solutions and Residuals	12 200	52 700	150	11 500	1 159 600
Miscellaneous Chemicals and Products	800	4 300	20	1 400	204 120
Paint and Organic Residuals	350	1 500	10	500	68 460
Aqueous Solutions with Organics	6 000	7 800	NA	10	65 310
Anion Complexes	150	50	10	10	40 550
Sludges and Inorganic Residuals	200	11 100	10	350	341 260
Pesticide and Herbicide Wastes	100	300	5	130	4 225
PCB Wastes	NA	NA	NA	NA	230
Clean-Up Residuals	50	450	1	20	19 220
Total	46 900	106 800	400	20 700	2 763 800

[1]Includes only those wastes that are reported for off-site management.
Source: Environment Canada, "Data on Hazardous Wastes, Rubber Wastes and Oil Wastes in Canada, 1983", unpublished.

question is difficult to quantify for several reasons:
1. There has not been an uniform definition as to what constitutes hazardous waste. What seems harmless today may be found to be hazardous tomorrow.
2. There has been no requirement to maintain records for on-site disposal of wastes.
3. Hazardous wastes are often included along with other wastes for municipal disposal.

This situation is changing. Efforts to co-ordinate their respective activities are being made by the Canadian Council of Resource and Environment Ministers (CCREM). A feasibility study on hazardous waste management in western and northern Canada has been completed. An inventory of hazardous waste management problems in the Atlantic provinces was completed in 1981. Ontario has established a provincial waste management agency, with a mandate to seek public participation in selecting sites. Quebec has established a solidification plant for inorganic wastes. Surveys of abandoned disposal sites are being undertaken by the federal government jointly with some provinces. Regulations governing the international and interprovincial movement of hazardous wastes have been developed under the authority of the *Transportation of Dangerous Goods Act*. Much work, however, is still required.

An October 1984 unpublished report, "Data on Hazardous Wastes, Rubber Wastes, and Oil Wastes in Canada - 1983", prepared by the Waste Management Branch of Environment Canada's Environmental Protection Service, provides an overview of various studies on hazardous wastes by federal and provincial authorities. This report, based on published information, includes an attempt to determine the annual quantities of wastes generated for each of a number of consolidated waste types. The report addresses primarily only those wastes requiring off-site management. The review identified gaps in the data and a large measure of inconsistency in the manner of data gathering and reporting. Nevertheless, efforts were made to standardize the available data and consolidate it in a common format.

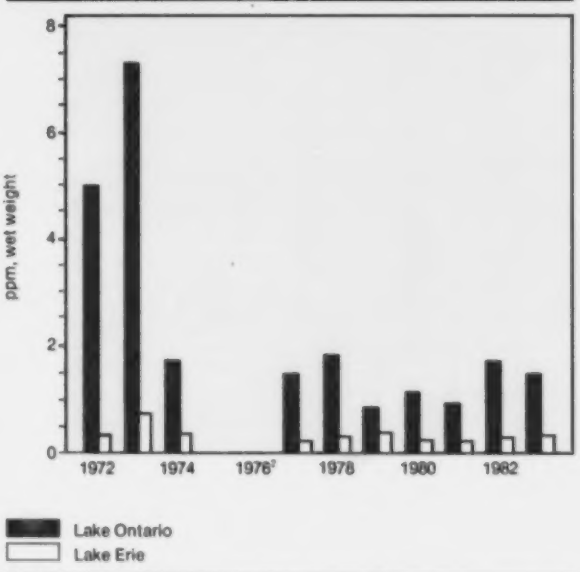
For this purpose, hazardous wastes were defined as those that, because of their nature and quantity, are potentially harmful to human health and/or the environment and that require special disposal techniques. Hazardous wastes may exhibit any of the following characteristics:

- explosiveness
- inflammability
- oxidation
- acute toxicity
- corrosiveness
- gas in a compressed state

A list of more than 3 000 dangerous goods with accompanying regulations was issued recently under the *Transportation of Dangerous Goods Act* (February 1985).

Table 8.17 summarizes, for the provinces and for

Figure 8.15
PCB Levels in Smelt from Lake Ontario and Lake Erie, 1972-1983[1]



[1] 1972-77 data: edible portion; 1977-1983 data: whole fish.
[2] No data collected.
Source: Great Lakes Water Quality Board, *Great Lakes Water Quality*, Reports to the International Joint Commission, 1981, 1985.

Canada, the quantities of hazardous wastes generated in 1982 by consolidated waste type. Overall, heavy metal solutions and residuals account for some 42 per cent of the quantities involved, solvents and organic solutions contribute 9 per cent, oil and grease account for 9 per cent, organic and oily residuals add 8 per cent, sludges and inorganic residuals make up 12 per cent, and 'other' contributes 20 per cent. Ontario accounts for about 51 per cent of the total and Quebec for 34 per cent.

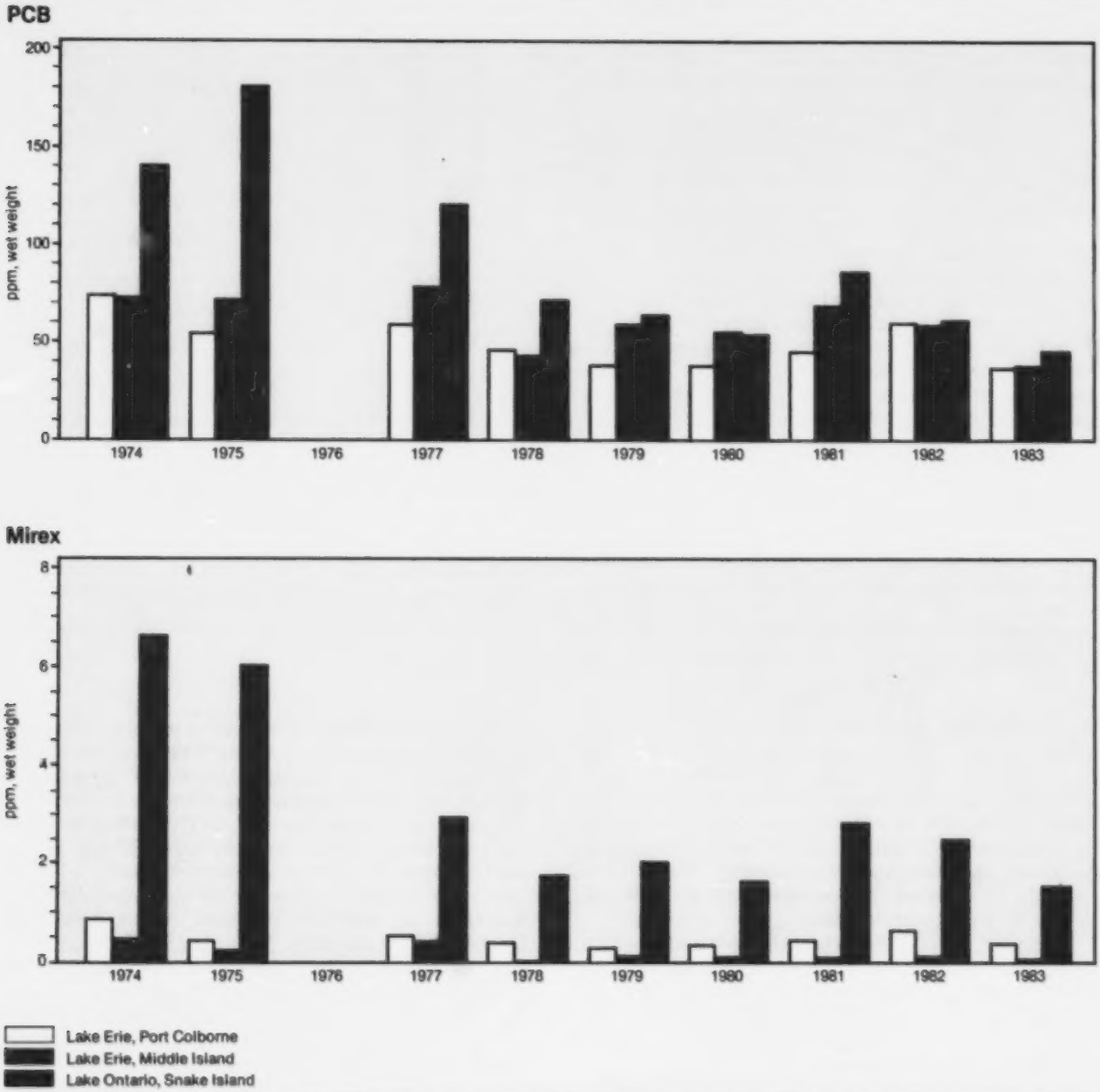
Studies of existing waste disposal sites are still going on. Some of these are joint federal-provincial studies but some, such as those in Ontario, Quebec and British Columbia, are limited to sites located on federal Crown land. These studies form part of a three-phase program as follows:

Phase I Identification and verification of the location of all active and inactive waste disposal sites, together with collection of available data on the nature and quantity of the materials deposited therein.

Phase II Preliminary assessment of sites identified in Phase I to determine the manifest or potential impact of each site.

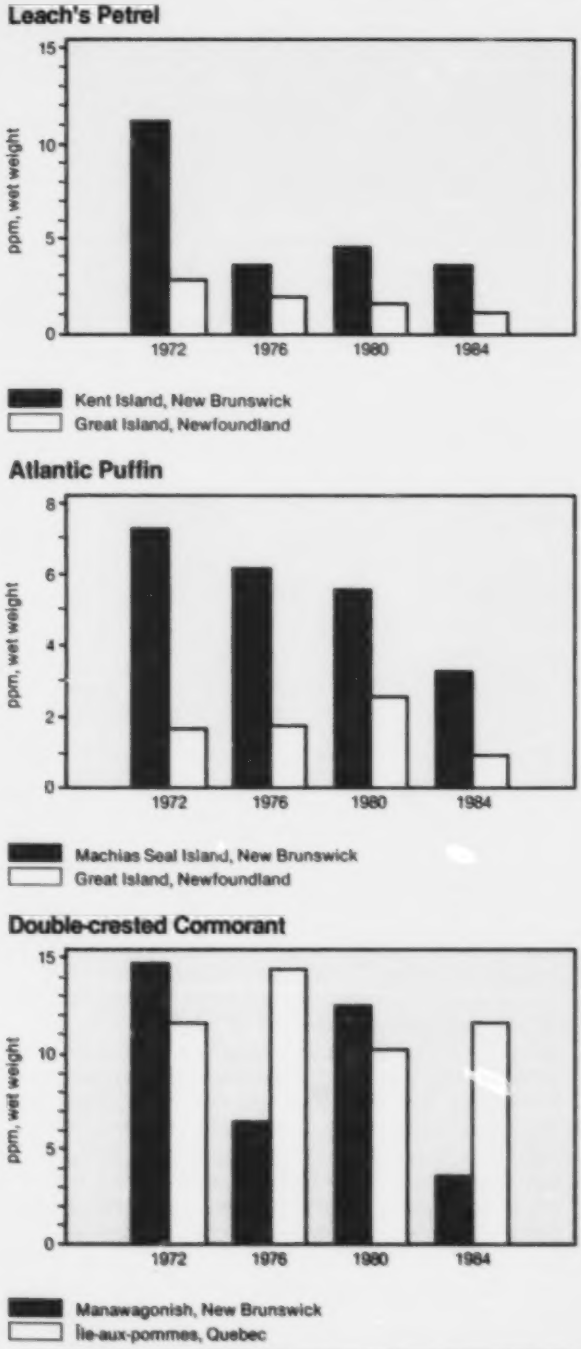
Phase III Detailed examination of high-priority sites to verify the preliminary assessment and determine the need for remedial action.

Figure 8.16
PCB and Mirex Levels in Herring Gull Eggs, Lower Great Lakes, 1974-1983



Source: 1974-77: D.V. Weseloh et al., "Organochlorine contaminants and trends in reproduction in Great Lakes Herring Gulls, 1974-78", Transactions of the 44th North American Wildlife and Natural Resources Conference, 1979.
1978-1983: Personal Communication, D.V. Weseloh, Canadian Wildlife Service, Ontario Region, Environment Canada, 1984, 1985.

Figure 8.17
PCB Levels in Eggs of Atlantic Coast Bird Species



Source: 1972, 1976: Peter A. Pearce et al., *Pesticides Monitoring Journal*, 13/2 (1979): 61-68.
1980, 1984: Personal Communication, D.B. Peakall, Canadian Wildlife Service, Environment Canada, 1984, 1985.

More specifically, the objectives of the Phase I studies were to

1. identify all active and inactive waste disposal sites that have accepted municipal, institutional, commercial or industrial wastes;
2. determine the ownership, duration and method of operation, type and quantity of waste deposited at each site;
3. identify land use in the area adjacent to the site;
4. evaluate the physical, geological and hydrogeological characteristics of the site; and
5. assign priorities to the sites based on the potential for adverse health and/or environmental effects.

Three levels of priority were agreed upon:

Priority 1 Sites that could present a high risk potential to health and the environment and that should be assessed immediately;

Priority 2 Sites that could present a medium risk potential and that should be assessed at a later date; and

Priority 3 Sites that should not present a danger to health or the environment, but that may require occasional monitoring in the future.

As of November 1985, some 5 493 active and inactive waste disposal sites of all three classes had been identified across Canada. Table 8.18 provides a summary of these findings. The table shows the number of active and inactive sites identified in each province or territory and the classes to which these sites are assigned. A significant number of sites have not yet been classified. A substantial number require further assessment immediately (Priority 1).

Spills and accidents are another way that petroleum, chemical and mineral products are inadvertently released into the environment. Information on these emergency events, provided by federal and provincial regulatory agencies, is stored in the database for the National Analysis of Trends in Emergencies System (NATES), maintained by Environment Canada. The number of contributing agencies has increased steadily over the years so that trends are biased by the growth in reporting. Some spills involve highly toxic substances; others may involve materials that either are degraded relatively quickly or pose less of an environmental threat. By their very nature, the number, size and location of spills vary greatly from year to year.

Studies following major oil tanker spills have generally shown short-term effects on wildlife and aquatic species followed by recovery to relatively normal conditions. Accidents such as the chlorine gas spill caused by a train derailment in Mississauga, Ontario (November 1979) resulted in the temporary displacement of large numbers of people.* Accidents such as the Union Carbide plant disaster in Bhopal,

*That no one died or was injured by one of the most serious chemical accidents in Canada was sheer luck. The explosion of the accompanying propane gas tanks generated sufficient heat to waft the chlorine gas into the high atmosphere, thus negating the natural tendency of this heavier-than-air, highly toxic gas to spread out at ground level.

Table 8.18
Distribution of Active and Inactive Waste Disposal Sites by Jurisdiction and Priority for Further Assessment

Province/ Territory	Site Status	Priority 1	Priority 2	Priority 3	Not Rated	Total
British Columbia[1]	Active	1	23	24	46	94
	Inactive	6	15	12	10	43
	Unknown				4	4
	Total	7	38	36	60	141
Alberta	Active	77	161	467	0	705
	Inactive	88	133	226	0	447
	Unknown				38	38
	Total	165	294	693	38	1 190
Saskatchewan	Active	78	603	188	89	958
	Inactive	19	109	83	155	366
	Total	97	712	271	244	1 324
Manitoba	Active	128	293	100	9	530
	Inactive	66	125	33	6	230
	Total	194	418	133	15	760
Ontario[1]	Active	1	2	92	0	95
	Inactive	6	14	105	0	125
	Total	7	16	197	0	220
Quebec[1]	Active	6	13	0	0	19
	Inactive	5	19	2	0	26
	Unknown				3	3
	Total	11	32	2	3	48
New Brunswick	Active				245	245
	Inactive	9	46	136	0	191
	Total	9	46	136	245	436
Nova Scotia	Active				70	70
	Inactive	15	123	34	0	172
	Total	15	123	34	70	242
Prince Edward Island	Active	7	87	150	0	244
	Inactive	4	44	169	0	217
	Total	11	131	319	0	461
Newfoundland[1]	Active	1	21	21	0	43
	Inactive	0	71	125	0	196
	Total	1	92	146	0	239
Northwest Territories	Active	15	42	50	0	107
	Inactive	3	22	58	0	83
	Unknown	2	3	2	235	242
	Total	20	67	110	235	432
Total Canada		537	1 989	2 077	910	5 493

[1]Federal lands only.
The inventory for Yukon is incomplete; however, 16 active Priority 3 sites have been identified to date.
Source: Personal Communication, Tom Foote, Environment Canada, Environmental Protection Service, Waste Management Branch.

Table 8.19
Highlights of Summary of Reported Emergency Events, 1974-79

	1974	1975	1976	1977	1978	1979
Number of Events Reported	891	1 484	1 071	1 418	1 899	2 189
% Share by:						
Tankers & other watercraft	15.7	5.5	5.7	6.4	4.7	3.6
Trains & motor vehicle transport	20.4	15.8	16.6	17.3	14.8	20.0
Pipelines	6.2	3.0	2.1	11.4	1.3	2.6
Mines & wells	1.1	38.9	49.8	37.9	49.9	48.8
Refineries, depots & service stations	8.6	4.4	7.5	11.9	15.4	13.9
Industrial plants	19.6	17.4	7.2	4.9	4.4	2.5
Amount Spilled (tonnes)	86 596	1 222 989	265 642[1]	72 769	205 168	105 401
% Share by:						
Tankers & other watercraft	4.5	0.1	1.0	2.0	0.7	8.8
Trains & motor vehicle transport	4.3	0.7	2.0	11.7	29.3	8.7
Pipelines	12.0	0.2	1.7	4.6	2.7	14.4
Mines & wells	11.8	62.1	5.6	16.0	18.1	29.9
Refineries, depots & service stations	2.0	0.4	0.8	5.9	33.5	2.7
Industrial plants	59.3	0.5	0.8	18.3	15.4	0.8
Amount of Petroleum Spilled (tonnes)	18 934	19 860	16 432	16 229	19 188	31 064
% Share as:						
Crude	52.9	50.8	58.6	54.1	48.0	37.5
Gasoline	4.2	11.7	9.3	4.1	5.5	4.5
No. 2 Fuel	2.9	3.0	5.9	18.4	12.0	12.8
No. 4 & No. 5 Fuel	29.9	16.9	12.2	9.1	10.0	5.7
No. 6 Fuel	5.3	11.1	10.2	4.2	15.9	28.6
Amount of Non-Petroleum Spilled (tonnes)	67 662	1 203 129	249 210	56 540	185 980	74 337
% Share as:						
Acids	0.1	0.2	0.5	1.1	2.7	0.2
Fertilizers	0.1	33.0	0.2	0.1	1.2	0.3
Minerals	1.2	61.8	0.9	1.2	2.0	2.2
Industrial chemicals	11.1	0.5	0.8	62.4	28.7	5.1
Industrial wastes	43.4	2.3	0.5	21.7	40.9	47.6
Salt water	14.7	0.1	2.8	7.5	5.2	0.1

[1] 'Other Sources' accounted for nearly 90 per cent of the amount spilled in 1976.
Source: Environment Canada, Environmental Protection Service, *Spill Technology Newsletter* for the relevant periods.

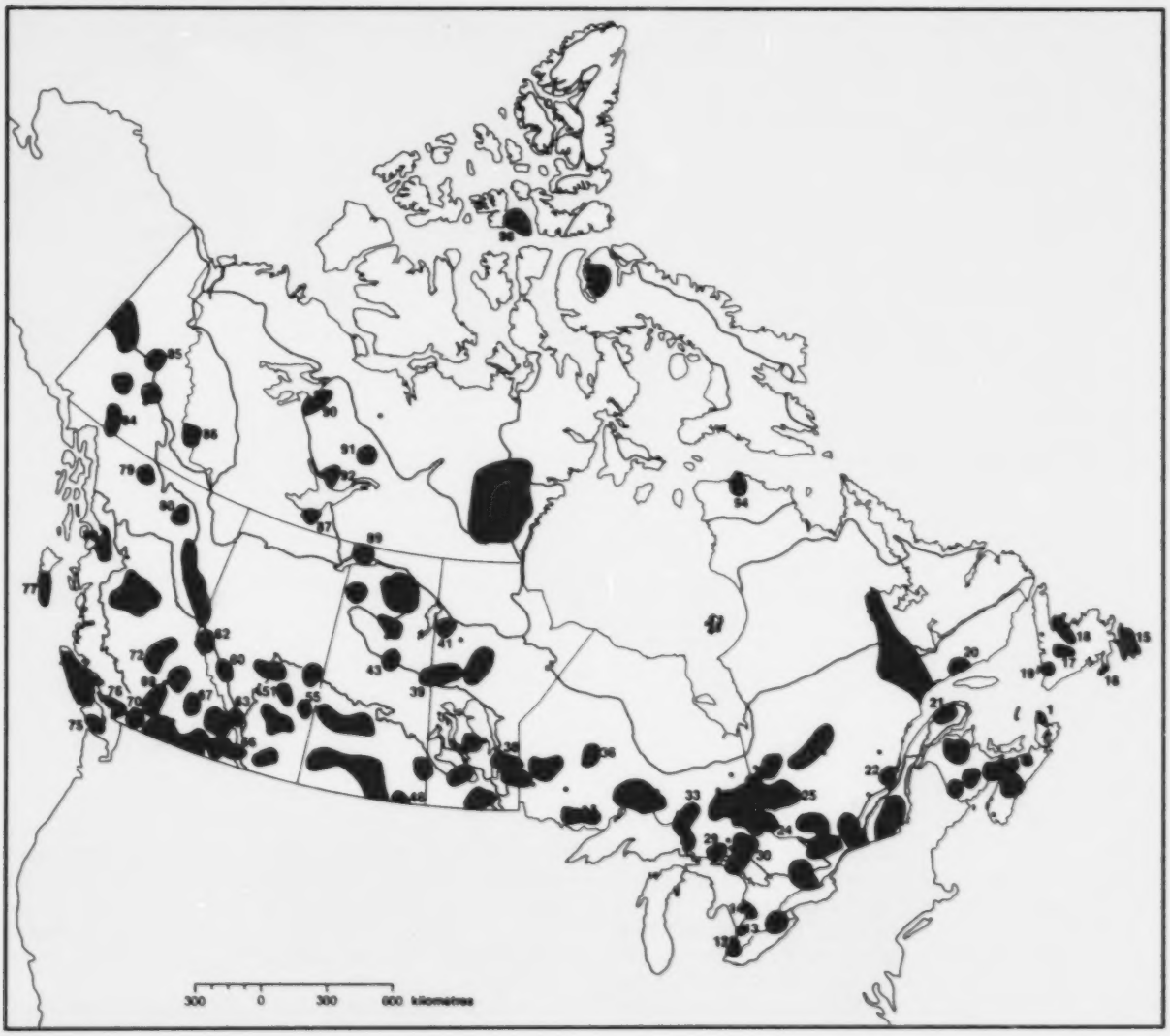
India (December 1984), where thousands died and many more were injured, serve to illustrate the potential risks associated with major accidents.

Table 8.19 shows a statistical distribution of the number and kind of environmental emergencies and the quantities of hazardous materials involved for the years 1974 to 1979. In 1974, industrial plants accounted for the largest amount of spilled material, mostly as industrial wastes. In all other years, mines and wells consistently reported the largest number of spills, and in 1975 this category accounted for by far the largest quantity spilled. The number of accidents reported for trains and motor vehicle transport was consistently in the range of 15 to 20 per cent, although with the exception of 1978, the quantities involved accounted for less than about 10 per cent of the total amount reported. Crude oil usually accounted for about half the total.

Another source of contamination is mining wastes. Such wastes include waste rock and fine particles discarded after recovery of the desired mineral. Mining operations typically haul vast quantities of inorganic substances to the surface and pile wastes (before refining) and tailings (after refining) in such a manner as to expose them to weathering and other natural processes. Concentrates of minerals leach into surface waters through runoff or percolate into underground waters. Elevated concentrations of these substances may be harmful to human health or to biological processes.

Data on the quantities of solid wastes produced in Canadian metal mines in 1981, and on their disposition, have been aggregated by ecozone and are presented in Table 8.20. Figure 8.18 shows the locations of major metal mine areas. Although mining activity varies with economic conditions, these data are considered to be representative of the pattern during the last five years. Not all mine wastes are deposited in tailings or waste heaps. Some are used as mine backfill and in road and yard maintenance or are shipped elsewhere for additional processing or other uses. These dispositions are also shown in the table. The amount of waste that ends up as tailings or waste ranges from around 25 per cent up to 100 per cent, but overall, about 80 per cent is disposed of this way. The quantity of solid waste is very large, but the bulk is usually waste rock. Nevertheless, a number of substances, such as arsenic, cadmium,

Figure 8.18
Location of Major Mining Areas



Mining Region
Number of Region
Metal Mine Active in 1983
Ecozone Boundary

List of Elements

Ag	— silver	Ni	— nickel
Au	— gold	Pb	— lead
Bi	— bismuth	Re	— rhenium
Ca	— calcium	Sb	— antimony
Cd	— cadmium	Se	— selenium
Ce	— cerium	Sn	— tin
Co	— cobalt	Ta	— tantalum
Cu	— copper	Te	— tellurium
Fe	— iron	Ti	— titanium
In	— indium	U	— uranium
Mg	— magnesium	W	— tungsten(wolfram)
Mo	— molybdenum	Zn	— zinc

Source: Environment Canada, Lands Directorate, *Mining, Land Use and the Environment*, by I.B. Marshall, 1982.
Energy, Mines and Resources Canada, *Principal Mineral Areas of Canada* (Map 900 A), 1983.

Key to Principal Mining Regions

Atlantic Maritime

1	Sydney–Cape Breton, N.S.	Coal, Gypsum
2	New Glasgow, N.S.	Coal
3	Wolfville–Stewiacke, N.S.	Gypsum, Pb, Zn, U
4	Moncton–Springhill, N.B.–N.S.	Coal, Salt, Gypsum
5	Minto, N.B.	Coal, Potash
6	Fredericton, N.B.	Sb
7	Bathurst, N.B.	Pb, Zn, Cu

Mixed-Wood Plain

8	Eastern Townships, Que.	Asbestos, Talc, Soapstone
9	Montreal, Que.	Silica, Magnesite, Magnesitic Dolomite
10	Ottawa Valley, Ont.–Que.	Mg, Ca
11	Hagersville, Ont.	Gypsum
12	Windsor, Ont.	Salt
13	Sarnia, Ont.	Salt
14	Goderich, Ont.	Salt

Boreal Shield

15	Avalon Peninsula, Nfld.	Pyrophyllite
16	St. Lawrence, Nfld.	Silica
17	Buchans, Nfld.	Zn, Pb, Cu, Ag, Au, Cd
18	Springdale–Baie Verte, Nfld.	Cu, Au, Ag, Asbestos
19	Stephenville, Nfld.	Gypsum
20	Havre St. Pierre, Que.	Fe, Ti
21	Gaspé, Que.	Cu, Mo
22	Baie St. Paul, Que.	Fe
23	Maniwaki, Que.	Ni, Cu, Fe
24	Belleterre, Que.	Ni, Cu
25	Noranda–Val d'Or, Que.	Cu, Zn, Ag, Au, Pb
26	Matagami, Que.	Zn, Cu
27	Chibougamau, Que.	Cu, Au, Ag
28	Bancroft–Marmora, Ont.	Talc, Nepheline Syenite, Dolomite, U
29	Elliot Lake, Ont.	U
30	Sudbury Basin, Ont.	Ni, Cu, Au, Ag, Platinum Metals, Co, Se, Te, Fe, U
31	Kirkland Lake–Cobalt, Ont.	Au, Ag, Fe
32	Timmins–Porcupine, Ont.	Zn, Cu, Au, Ag, Pb, Sn, Cd
33	Algoma, Ont.	Fe
34	Long Lac, Ont.	Cu, Zn, Ag, Pb, Au
35	Steep Lake, Ont.	Fe, Ni, Cu
36	Pickle Crow, Ont.	Cu, Ni, Ag
37	Red Lake, Ont.	Au, Cu, Zn, Ag, Fe
38	Bissett–Black Island, Man.	Silica
39	Flin Flon–Snow Lake, Man.	Cu, Zn, Au, Ag, Pb, Cd, Se, Te
40	Thompson, Man.	Ni, Cu, Co, Precious Metal Residues
41	Lynn Lake, Man.	Cu, Zn, Ag
42	Lac du Bonnet, Man.	Ta, Ce
43	La Ronge, Sask.	Cu, Ni, Zn, Pb

Prairie

44	Morris–Morden, Man.	Bentonite
45	Neepawa, Man.	Gypsum
46	Estevan–Bienfait, Sask.	Coal
47	Regina–Moose Jaw, Sask.	Sodium Sulphate, Potash, Salt, Bentonite
48	Saskatoon, Sask.	Potash, Sodium Sulphate, Salt
49	Esterhazy, Sask.	Potash
50	Edmonton, Alta.	Coal, Barite, Silica
51	Forestburg, Alta.	Coal, Bentonite
52	Drumheller, Alta.	Coal
53	Lethbridge, Alta.	Coal
54	Lindbergh, Alta.	Salt
55	Metiskow, Alta.	Sodium Sulphate

Boreal Plain

56	Gypsumville, Man.	Gypsum
57	Key Lake, Sask.	U
58	Cluff Lake, Sask.	U
59	Athabasca Sandstone–Rabbit Lake, Sask.	U
60	Luscar, Alta.	Coal
61	Peace River, B.C.	Coal

Montane Cordillera

62	Grande Cache, Alta.	Coal
63	Canmore, Alta.	Coal
64	Invermere, B.C.	Barite, Gypsum
65	Kimberley, B.C.	Pb, Zn, Ag, Sb, Cd, Bi, Sn, In
66	Coleman–Crow's Nest, Alta–B.C.	Coal
67	Revelstoke, B.C.	Ag, Zn, Pb
68	Trail–Princeton, B.C.	Cu, Mo, Ag, Au, Pb, Zn
69	Highland Valley, B.C.	Cu, Mo, Ag, Au
70	Hope, B.C.	Cu, Au, Ag
71	Birch Island, B.C.	U
72	Caribou, B.C.	Cu, Mo, Ag
73	Central B.C.	Cu, Au, Ag, Mo

Pacific Maritime

74	Vancouver Island, B.C.	Cu, Mo, Au, Ag, Phb, Zn, Re
75	River Jordan, B.C.	Cu
76	Britannia Beach, B.C.	Au, Ag, Pb, Zn, Cd
77	Queen Charlotte Islands, B.C.	Fe, Cu, Ag
78	Stewart, B.C.	Cu

Boreal Cordillera

79	Cassiar, B.C.	Asbestos
80	Fort Nelson, B.C.	Cu, Pb, Zn
81	Clinton Creek, Yukon	Asbestos
82	Carmacks, Yukon	Coal
83	Faro, Yukon	Pb, Zn, Ag, Cu, Cd
84	Whitehorse–Carcross, Yukon	Cu, Au, Ag

Tundra Cordillera

85	Mayo, Yukon	Ag, Pb, Zn, Cd
86	Tungsten, NWT	W, Cu

Taiga Plain

87	Pine Point, NWT	Zn, Pb

Taiga Shield

88	Labrador, Que.–Nfld.	Fe
89	Uranium City, Sask.	U
90	Great Bear Lake, NWT	Ag, Cu
91	Mackay Lake, NWT	Au, Base Metals
92	Yellowknife, NWT	Au

Southern Arctic

93	Baker Lake, NWT	U

Northern Arctic

94	Purtuniq–Hudson Strait, Que.	Asbestos
95	Arctic Bay, NWT	Pb, Zn, Ag
96	Little Cornwallis Island, NWT	Zn, Pb

Table 8.20
Disposition of Solid Wastes from Metal Mines in Canada, 1981

Ecozone	Number of Establishments	Solid Waste[1] Total Quantity Disposed[3] (000s tonnes)	% Mine Backfill	% Transferred to Waste Heap	% Other[2]
1 Tundra Cordillera	1	200-600[4]	15.80	84.20	0
2 Boreal Cordillera	6	33 528	0.02	99.98	0
3 Pacific Maritime	7	51 122	0.26	70.54	29.20
4 Montane Cordillera	21	263 845	0.01	75.24	24.75
5 Boreal Plain	3	2 600-5 300	6.60	93.40	0
6 Taiga Plain	1	12 500-25 000	73.82	26.18	0
7 Prairie	0				
8 Taiga Shield	10	45 149	0.45	99.53	0.02
9 Boreal Shield	67	127 964	9.46	86.34	4.20
10 Hudson Bay Plain	0				
11 Mixed-Wood Plain	0				
12 Atlantic Maritime	8	11 551	5.67	94.01	0.32
13 Southern Arctic	0				
14 Northern Arctic	1	300-700		100	0
15 Arctic Cordillera	0				
Canada	125	548 759-564 759	2.45	81.43	16.12

[1]Solid waste includes rock and fine particles discarded following concentration and recovery of the desired mineral.
[2]Other includes tailing and residues and waste rock used for road and yard maintenance, shipped for sale or sold to others.
[3]Total quantity disposed includes rock waste hoisted or removed from mining and tailings and residues (from own and custom-treated purchased ores).
[4]Ranges are used to meet the confidentiality restrictions of the *Statistics Act*.
Source: Energy, Mines and Resources, "Annual census of mines, quarries and sand pits", 1981. Special tabulation by Statistics Canada.

lead and mercury, may also be present in sufficient quantity to be of environmental concern.

Lead and mercury are also released into the environment as air pollutants by industrial processes, fuel combustion, and a variety of miscellaneous activities. Data obtained from the 1978 and 1982 inventory studies of sources and emissions of mercury and lead respectively have been summarized and compiled in Table 8.21. With the displacement of leaded by unleaded gasoline (Table 8.22) it is projected that transportation will contribute less lead to the environment in the future, although it is currently the largest single source of lead emissions.

Before the advent of organochlorine pesticides in the late 1960s, a number of other pest control products and agricultural practices resulted in the contamination of certain agricultural soils with arsenic, lead and mercury. Lead arsenate was widely used as an insecticide in apple and cherry orchards, and various mercuric salts were used as fungicides. Measurements for arsenic, cadmium, lead and mercury in a variety of Ontario agricultural soil samples collected between 1972 and 1975 are summarized in Table 8.23. Higher concentrations of arsenic, lead and mercury were observed in those soils where crops had been treated with compounds containing these elements.[2] The presence of cadmium in the soil was associated, at least in part, with the application of sewage sludge in previous years; two such known cases produced very high cadmium concentrations.

The full NAQUADAT database was also searched for the presence of data concerning arsenic, cadmium, lead and mercury. As with other NAQUADAT data searches, the intent was to determine, for each specified basin and each time interval, the number of recorded entries and the number (and percentage) of observations that exceeded either of two pre-selected concentration figures. The higher figure (e.g., 50 μg/L for arsenic) was drawn from published guidelines for water quality. The lower figure is usually one-fifth the maximum acceptable concentration, except in the case of cadmium (see below). Table 8.24 summarizes published water guidelines for these four inorganic substances. The pre-selected concentration figures for these were as follows:

arsenic: 50 μg/L and 10 μg/L
lead: 50 μg/L and 10 μg/L
mercury: 1.0 μg/L and 0.2 μg/L
cadmium: 10 μg/L and 5 μg/L

The detection limit for some of the cadmium measurements was only 10 μg/L, so that the column headed >5 μg/L is an under-estimate. Tables 8.25 to 8.28 summarize the results of these NAQUADAT searches.

Not all drainage basins were sampled for arsenic in each of the three-year intervals (Table 8.25 and Figure 8.19). In this case, it is more difficult to identify time trends. Where results were available for all time periods (e.g., data for Hudson Bay, Lake Winnipeg, Saskatchewan River and Mackenzie River), the percentage of samples exceeding the specified limits certainly decreased. There was little change in

Text continues on page 200.

Table 8.21
Highlights from National Inventory of Sources and Emissions of Lead and Mercury

Contaminant	Sector	Tonnes	Percentage of Total
Lead	**Industrial Processes**	**4 006**	**34.94**
	Primary Copper/Nickel Production	1 706	14.88
	Mining, Milling and Concentration of Lead-bearing Ores	964	8.41
	Primary Iron and Steel Production	600	5.23
	Primary Lead and Zinc Production	304	2.66
	Ferrous Foundries	212	1.85
	Other Industries	220	1.91
	Fuel Combustion: Transportation Sources	**7 236**	**63.11**
	Gasoline-powered Motor Vehicles	7 000	61.05
	Aircraft	173	1.51
	Gasoline Marketing	63	0.55
	Fuel Combustion: Stationary Sources	**25**	**0.22**
	Power Generation	14	0.12
	Industrial/Commercial/Residential Fuel Combustion	11	0.10
	Solid Waste Incineration	**199**	**1.73**
	Waste Oil Incineration	130	1.13
	Municipal Refuse Incineration	67	0.58
	Sewage Sludge Incineration	2	0.02
	Total	11 466	100.00
Mercury	**Industrial Processes**	**20**	**50.0**
	Base Metal Recovery	2.4	6.0
	Chloralkali Industry	16.34	40.8
	Others	1.28	3.2
	Fuel Combustion: Stationary Sources	**9.08**	**22.7**
	Coal Combustion	5.04	12.6
	Petroleum Combustion	2.76	6.9
	Other Sources	1.28	3.2
	Miscellaneous	**10.92**	**27.3**
	Paint Application	4.8	12.0
	Municipal Incineration	1.64	4.1
	Fluorescent Tube Breakage	3.4	8.5
	Other	1.08	2.7
	Total	40	100.0

Source: Environment Canada, *National Inventory of Sources and Releases of Lead*, EPS 5/HA/3, 1985.
Environment Canada, *National Inventory of Sources and Emissions of Mercury*, EPS 3-AP-81-1, 1983.

Table 8.22
Characteristics of Fuel Type and Passenger Car Size

Model Year Class	% of Personal Use by Number of Cylinders			% Total Fuel Consumed by Model Year & Fuel Type	
	8	6	4	leaded	unleaded
1978 and earlier	59.9	19.3	20.5	51.4	48.3
1979	50.9	20.9	26.8	13.1	85.4
1980	36.1	30.0	33.4	10.7	87.5

Source: Statistics Canada, *Fuel consumption survey*, Annual Report, October 1979–September 1980 (Ottawa: 1983).
Statistics Canada, *Fuel consumption survey*, Annual Report, October 1980–September 1981 (Ottawa: 1984).

Table 8.23
Contamination of Agricultural Soils in Ontario, 1972-75

Contaminant	Number of Measurements	Concentration (ppm dried soil) Mean	Range
Arsenic			
Apples, cherries, potatoes	89	26.5	1.66-91.6
Other crops	207	6.27	1.10-16.7
All soils	296	12.4	1.10-91.6
Cadmium			
All soils	296	0.56	0.10-8.10
Lead			
Tree & vine fruit soils	86	123.0	4.40-888.0
Other crops	210	14.1	1.50-50.1
All soils	296	45.8	1.50-888.0
Mercury			
Vegetable organic soils, apples	44	0.33	0.03-1.14
Other crops	252	0.08	0.01-0.78
All soils	296	0.11	0.01-1.14

Soils collected to represent all types of crop production. Each sample a composite of samples from 10-20 randomly selected sites and to a depth of 15 cm at each location.

86 samples from orchards & vineyards, 82 from vegetable producing farms, 126 from hay & cash crops and 15 from unimproved pastures.

Crops had been treated with various fertilizers and pesticides for various periods of time.

Contamination levels vary with crop, with soil types and with treatment conditions.

Source: R. Frank et al., "Metals in Agricultural Soils of Ontario", *Canadian Journal of Soil Science* 56 (1976): 181-196.

Table 8.24
Water Guidelines for Metals
(micrograms per litre)

Substance	Drinking Water (Maximum Acceptable)	Raw Water	Protection of Freshwater Aquatic Life
Arsenic	50	50	50
Cadmium	5	10	0.2
Lead	50	250[1] 50	5-30[2]
Mercury	1	1	0.2[3] 0.1

[1]250 μg/L for conventional water treatment, 50 μg/L for disinfection only.
[2]The figure varies depending on water hardness and the presence or absence of sensitive species of fish.
[3]0.2 μg/L permitted where fish are not eaten.
Source: Health and Welfare Canada, *Guidelines for Canadian Drinking Water Quality* (Ottawa: 1978).
Environment Canada, *Guidelines for Surface Water Quality*, Volume 1, Inorganic Chemical Substances (Ottawa: 1979).

Table 8.25
NAQUADAT Water Quality Data — Arsenic[1]

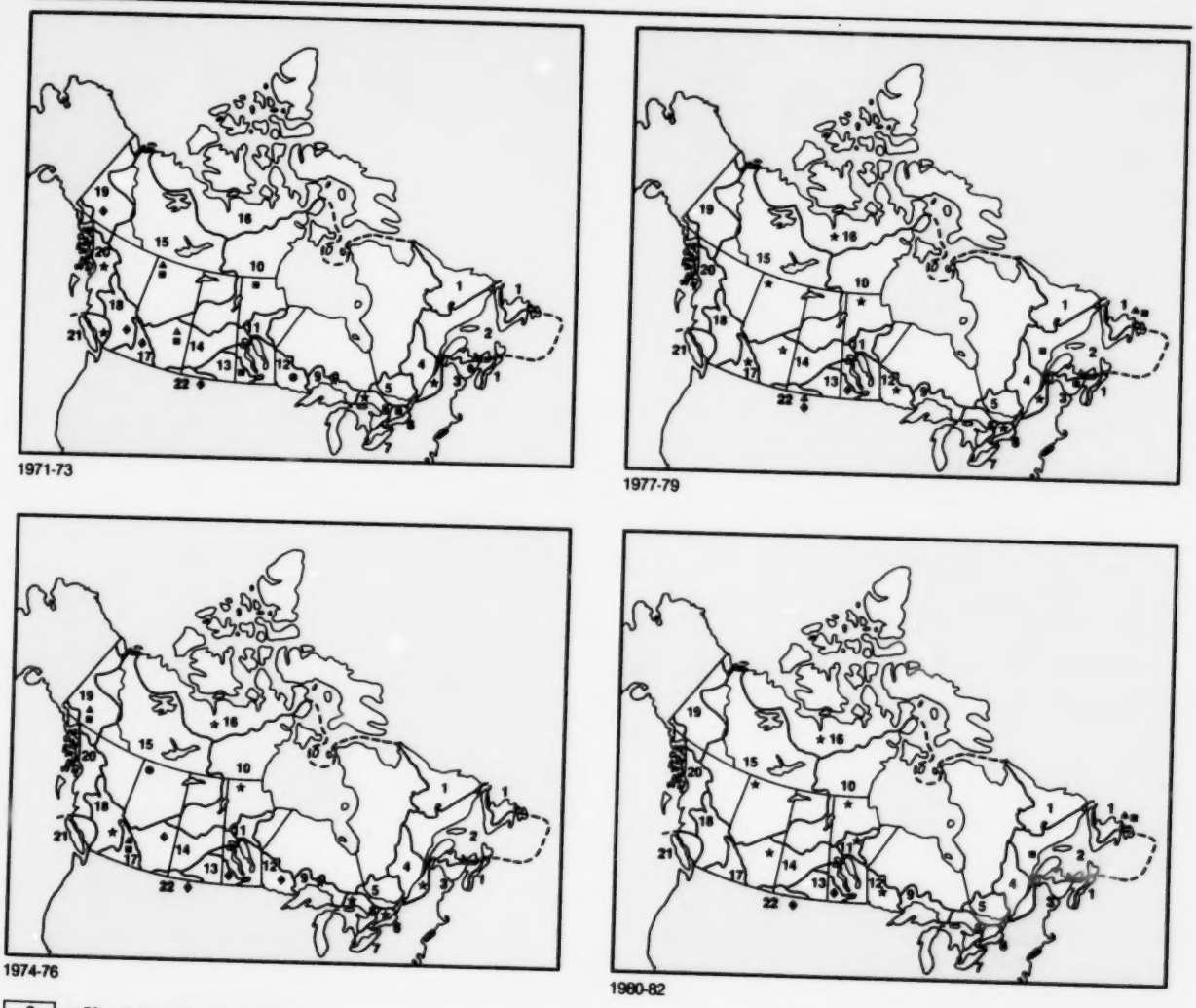
Drainage Basin	1971-73			1974-76			1977-79			1980-82		
	Number of Samples	% of samples >10 µg/L	% of samples >50 µg/L	Number of Samples	% of samples >10 µg/L	% of samples >50 µg/L	Number of Samples	% of samples >10 µg/L	% of samples >50 µg/L	Number of Samples	% of samples >10 µg/L	% of samples >50 µg/L
1 Atlantic Coast	—			—			80	41.2	1.2	45	35.6	4.4
2 Gulf of St. Lawrence	—			—			146	48.6	0	22	45.4	0
3 Bay of Fundy	24	8.3	0	—			154	43.5	0	—		
4 St. Lawrence River	184	0	0	164	0	0	163	0	0	—		
5 Ottawa River	—			—			—			—		
6 Lake Ontario	8	12.5	0	296	0	0	59	0	0	—		
7 Lake Erie/St. Clair	—			—			—			—		
8 Lake Huron	119	0	0	230	0	0	—			—		
9 Lake Superior	25	0	0	138	0	0	—			—		
10 Hudson Bay	87	16.1	0	170	0	0	522	0	0	183	0	0
11 Nelson River[2]	1	0	0	—			—			12	0	0
12 Lake Winnipeg	508	81.5	61.4	214	0.9	0	292	0	0	330	0	0
13 Assiniboine River	294	20.7	0	500	7.2	0	240	2.5	0	175	4.6	0
14 Saskatchewan River	588	19.6	0.2	691	0.1	0	509	0	0	792	0	0
15 Mackenzie River	755	25.3	6.1	605	13.7	11.2	150	0	0	405	0	0
16 Arctic Ocean	3	0	0	133	0	0	25	0	0	66	0	0
17 Columbia River	35	2.9	0	292	13.3	1.0	62	0	0	—		
18 Fraser River	19	5.3	0	10	0	0	—			—		
19 Yukon River	102	5.9	0	56	17.9	3.6	—			—		
20 Pacific North Coast	23	0	0	3	0	0	—			—		
21 Pacific South Coast	6	0	0	5	0	0	—			—		
22 Milk River	35	0.2	0	83	9.6	0	217	1.8	0.5	209	1.0	0
Total	2 816	28.9	12.7	3 590	5.0	2.0	2 619	6.9	0.1	2 239	1.6	0.1

[1]NAQUADAT parameter codes for dissolved arsenic, 33101, 33103 and 33105 were combined to produce this table. These codes refer to the colourimetric method of analysis in which the detection limit is 5 µg/L.

[2]For water basins 11-14, the prescribed search parameters were 20 and 50 µg/L, because some of the samples were analyzed using a method with a higher detection limit.

Source: Environment Canada, NAQUADAT database.

Figure 8.19
Arsenic in Major Drainage Basins in Canada


1971-73
1977-79
1974-76
1980-82
> 50 µg/L in > 10% of samples
> 50 µg/L in < 10% of samples
> 10 µg/L in > 10% of samples
> 10 µg/L in < 10% of samples
< 10 µg/L in all samples
Minimum of 6 samples per drainage basin
770 0 770 1540 kilometres

Source: Environment Canada, NAQUADAT Database.

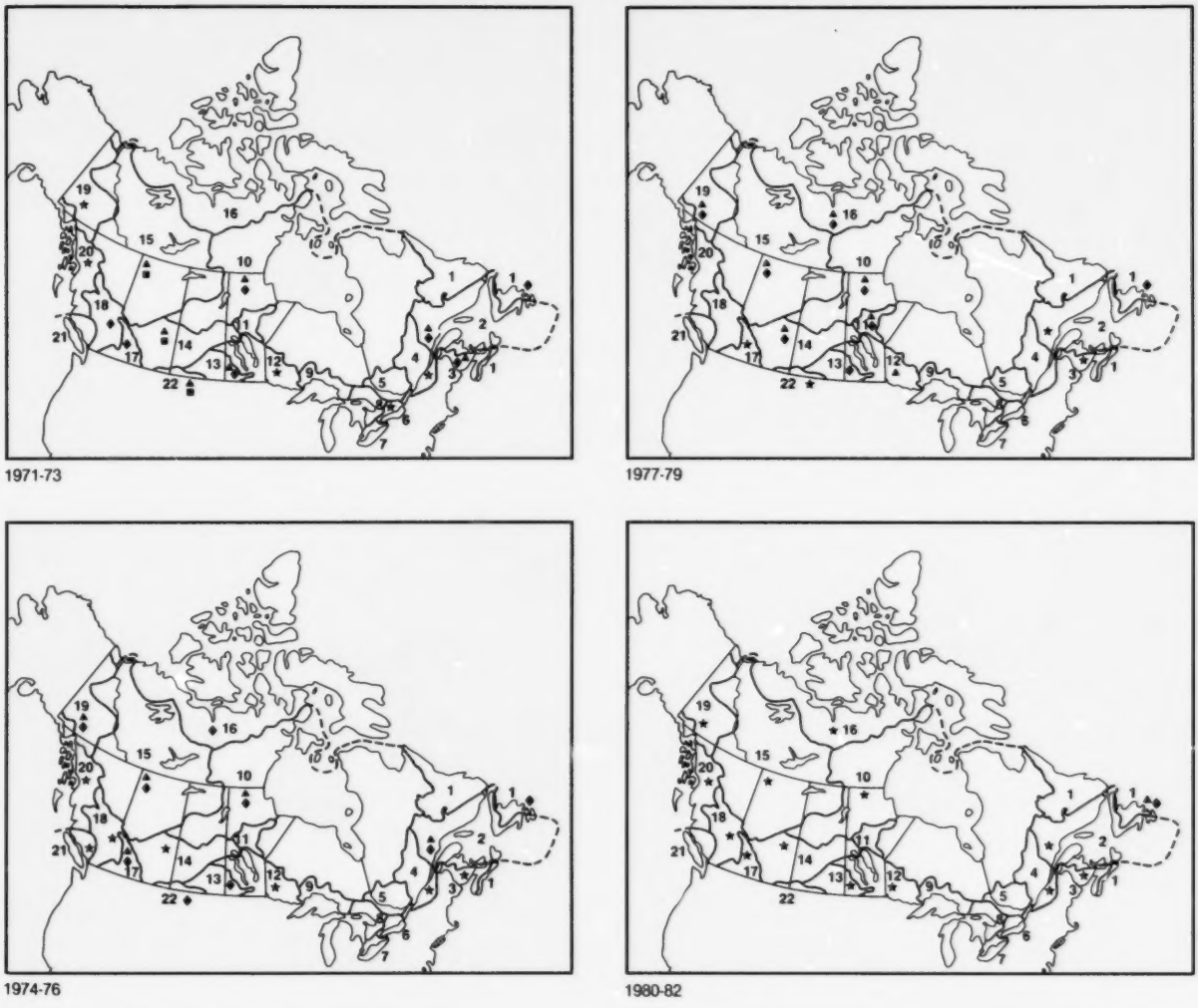
Table 8.26
NAQUADAT Water Quality Data — Cadmium[1]

Drainage Basin	1971-73			1974-76			1977-79			1980-82		
	Number of Samples	% of samples >10 µg/L	% of samples >5 µg/L	Number of Samples	% of samples >10 µg/L	% of samples >5 µg/L	Number of Samples	% of samples >10 µg/L	% of samples >5 µg/L	Number of Samples	% of samples >10 µg/L	% of samples >5 µg/L
1 Atlantic Coast	435	7.8	0	152	0.7	0	185	1.1	0	2 192	0.1	0.1
2 Gulf of St. Lawrence	2 575	4.3	0.3	1 166	2.2	0.6	363	0	0	517	0	0
3 Bay of Fundy	2 199	4.3	0.7	382	0	0	667	0	0	573	0	0
4 St. Lawrence River	547	0	0	33	0	0	—			36	0	0
5 Ottawa River	3	0	0	—			—			—		
6 Lake Ontario	7	0	0	—			—			—		
7 Lake Erie/St. Clair	—			—			—			—		
8 Lake Huron	—			—			—			—		
9 Lake Superior	—			—			—			—		
10 Hudson Bay	155	8.4	0.6	293	2.0	1.0	175	1.1	0.6	15	0	0
11 Nelson R.	6	0	0	42	0	0	32	3.1	3.1	2	0	0
12 Lake Winnipeg	147	0	0	221	0	0	194	1.0	0.5	15	0	0
13 Assiniboine River	416	3.4	1.7	518	0.4	0	184	0.5	0	10	0	0
14 Saskatchewan River	1 024	27.6	1.5	709	0	0	421	0.2	0.2	32	0	0
15 Mackenzie River	1 017	15.7	1.3	792	1.6	0.4	223	0.4	0.4	20	0	0
16 Arctic Ocean	2	0	0	192	6.2	0	33	6.1	3.0	6	0	0
17 Columbia River	52	5.8	0	337	5.6	4.7	61	0	0	356	0	0
18 Fraser River	270	0.4	0	20	0	0	—			11	0	0
19 Yukon River	11	0	0	186	5.4	1.1	40	5.0	5.0	55	0	0
20 Pacific North Coast	17	0	0	29	0	0	—			90	0	0
21 Pacific South Coast	4	0	0	13	0	0	—			3	0	0
22 Milk River	51	25.5	2.0	88	2.3	0	122	0	0	3	0	0
Total	8 938	8.1	0.7	5 173	1.8	0.6	2 700	0.5	0.3	3 936	0.1	0.1

[1]NAQUADAT parameter codes for extractable cadmium, 40301 and 40302, were combined to produce this table. The analytical methods involved had detection limits of 10 and 1 µg/L respectively so that the data in the columns for 5 µg/L will underestimate this percentage.

Source: Environment Canada, NAQUADAT database.

Figure 8.20
Cadmium in Major Drainage Basins in Canada


1971-73
1977-79
1974-76
1980-82
▲ > 10 µg/L in < 10% of samples
■ > 5 µg/L in > 10% of samples
◆ > 5 µg/L in < 10% of samples
★ < 5 µg/L in all samples
Minimum of 6 samples per drainage basin
770 0 770 1540 kilometres

Source: Environment Canada, NAQUADAT Database.

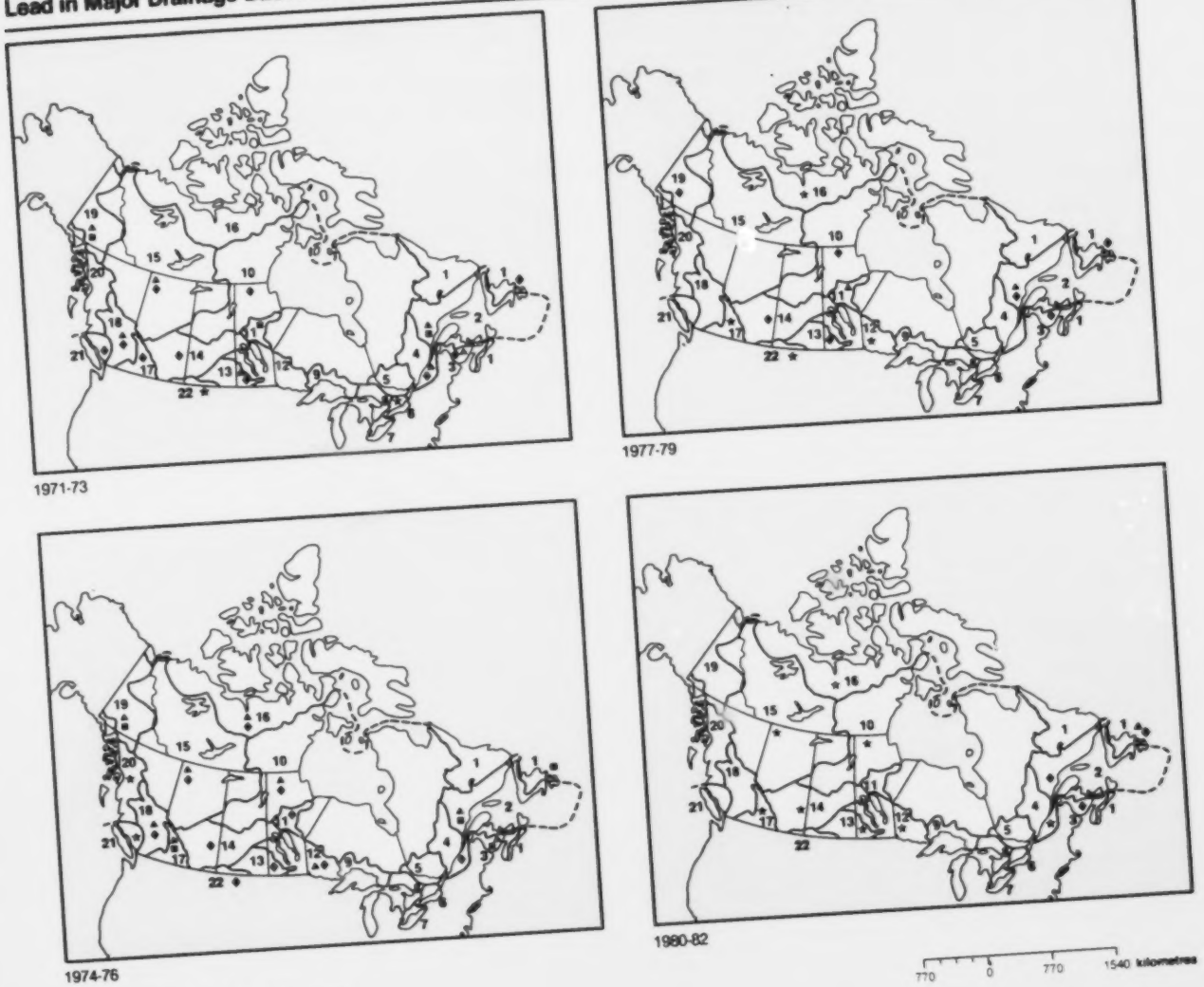
Table 8.27
NAQUADAT Water Quality Data — Lead[1]

Drainage Basin	1971-73			1974-76			1977-79			1980-82		
	Number of Samples	% of samples >10 µg/L	% of samples >50 µg/L	Number of Samples	% of samples >10 µg/L	% of samples >50 µg/L	Number of Samples	% of samples >10 µg/L	% of samples >50 µg/L	Number of Samples	% of samples >10 µg/L	% of samples >50 µg/L
1 Atlantic Coast	477	2.9	0	78	23.1	0	204	0.5	0	2 423	1.7	0.1
2 Gulf of St. Lawrence	3 292	11.7	1.6	1 212	21.4	1.9	369	0.5	0.3	523	0.4	0
3 Bay of Fundy	1 874	5.5	0.6	653	30.5	0.2	768	0.4	0	606	0.3	0
4 St. Lawrence River	548	6.2	0.5	35	2.9	0	—			33	0	0
5 Ottawa River	—			—			—			—		
6 Lake Ontario	8	0	0	2	0	0	—			—		
7 Lake Erie/St. Clair	—			—			—			—		
8 Lake Huron	—			—			—			—		
9 Lake Superior	—			—			—			—		
10 Hudson Bay	158	8.2	0	362	3.9	0.6	190	0.5	0	15	0	0
11 Nelson River	10	10.0	0	65	4.6	0	32	3.1	3.1	2	0	0
12 Lake Winnipeg	148	1.4	0	245	4.9	0.8	212	0	0	15	0	0
13 Assiniboine River	415	7.0	0.7	554	3.4	0	204	0.5	0	12	0	0
14 Saskatchewan River	1 163	5.0	0	902	1.8	0	634	1.1	0	39	0	0
15 Mackenzie River	1 026	8.4	0.4	846	2.2	0.1	296	1.7	0	22	0	0
16 Arctic Ocean	2	0	0	192	4.7	1.6	31	0	0	6	0	0
17 Columbia River	97	9.3	0	481	11.2	4.2	109	0	0	115	0	0
18 Fraser River	390	5.1	0.5	1 280	0.9	0.2	—			2	0	0
19 Yukon River	176	14.2	1.7	369	10.6	0.5	336	2.1	0	—		
20 Pacific North Coast	19	0	0	52	0	0	—			5	0	0
21 Pacific South Coast	19	5.3	0	16	0	0	—			1	0	0
22 Milk River	51	0	0	87	1.1	0	142	0	0	3	0	0
Total	9 873	7.9	0.8	7 431	9.1	0.8	3 527	0.8	0.1	3 822	1.2	0.1

[1]NAQUADAT parameter codes for extractable lead, 82302 through 82306, were combined to produce this table. The analytical method has a detection limit of 1 µg/L.

Source: Environment Canada, NAQUADAT database.

Figure 8.21
Lead in Major Drainage Basins in Canada



Minimum of 6 samples per drainage basin

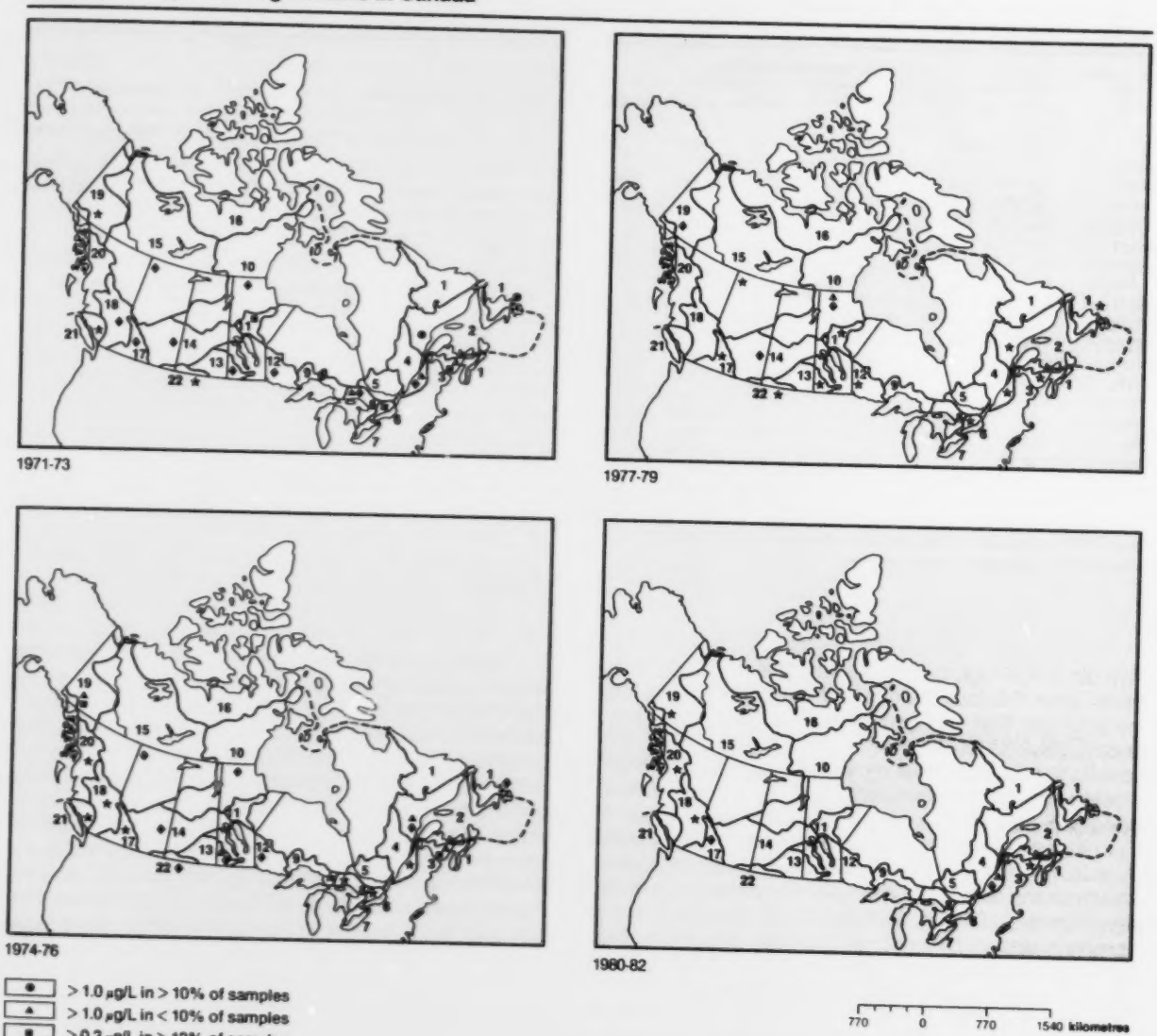
Source: Environment Canada, NAQUADAT Database.

Table 8.28
NAQUADAT Water Quality Data — Mercury[1]

Drainage Basin	1971-73			1974-76			1977-79			1980-82		
	Number of Samples	% of samples >10 µg/L	% of samples >50 µg/L	Number of Samples	% of samples >10 µg/L	% of samples >50 µg/L	Number of Samples	% of samples >10 µg/L	% of samples >50 µg/L	Number of Samples	% of samples >10 µg/L	% of samples >50 µg/L
1 Atlantic Coast	8	100	37.5	174	6.9	0	22	0	0	—		
2 Gulf of St. Lawrence	319	38.9	10.7	806	5.3	0.5	30	0	0	—		
3 Bay of Fundy	379	22.7	2.1	822	12.2	2.2	117	0	0	15	0	0
4 St. Lawrence River	568	3.2	0.7	201	0	0	151	0	0	86	3.5	2.3
5 Ottawa River	—			—			—			—		
6 Lake Ontario	12	16.7	0	249	0	0	84	0	0	—		
7 Lake Erie/St. Clair	—			—			—			—		
8 Lake Huron	121	8.3	7.4	230	0	0	—			—		
9 Lake Superior	25	20.0	16.0	132	0	0	—			—		
10 Hudson Bay	113	1.8	0	118	0.8	0	384	2.1	0.3	—		
11 Nelson River	11	18.2	0	—			8	0	0	—		
12 Lake Winnipeg	100	1.0	0	209	1.4	0	256	0	0	—		
13 Assiniboine River	360	1.9	0	409	1.2	0.2	206	0	0	—		
14 Saskatchewan River	572	0.9	0	764	0.7	0	502	0.2	0	—		
15 Mackenzie River	249	0.8	0	485	0.2	0	140	0	0	—		
16 Arctic Ocean	—			—			—			—		
17 Columbia River	174	2.3	0	335	0	0	86	0	0	283	0.7	0
18 Fraser River	383	2.3	0	66	0	0	—			11	0	0
19 Yukon River	19	0	0	82	13.4	6.1	44	2.3	0	48	0	0
20 Pacific North Coast	4	0	0	24	0	0	—			61	0	0
21 Pacific South Coast	19	0	0	18	0	0	—			3	0	0
22 Milk River	27	0	0	78	1.3	0	234	0	0	—		
Total	3 443	8.3	1.8	5 202	3.5	0.5	2 264	0.4	0.1	505	1.0	0.4

[1]NAQUADAT parameter codes for extractable mercury, 80311 through 80313, were combined to produce this table. The analytical method has a detection limit of 0.05 µg/L.
Source: Environment Canada, NAQUADAT database.

Figure 8.22
Mercury in Major Drainage Basins in Canada


1971-73
1977-79
1974-76
1980-82
> 1.0 µg/L in > 10% of samples
> 1.0 µg/L in < 10% of samples
> 0.2 µg/L in > 10% of samples
> 0.2 µg/L in < 10% of samples
< 0.2 µg/L in all samples
Minimum of 6 samples per drainage basin
770 0 770 1540 kilometres

Source: Environment Canada, NAQUADAT Database.

Table 8.29
Mercury Levels in Walleye, Selected Lakes in Ontario
(total mercury, ppm wet weight)

	English-Wabigoon River System											
	Clay Lake			Ball/Separation/Tetu Lakes			Lake St. Clair			Lake Simcoe		
	N	Mean	Range	N	Mean	Range	N	Mean	Range	N	Mean	Range
1970	26	4.86	1.02-9.63	4	1.79	0.50-2.24	615	2.10	0.23-14.00	22	0.26	0.07-0.96
1971	27	8.70	1.82-14.19	48	2.96	0.80-6.22	350	1.80	0.13-13.10	12	0.55	0.18-2.04
1972	24	7.67	NA	40	2.78	NA	436	1.30	0.13-7.10	—		
1973	—			47	1.67	0.35-2.97	291	1.10	0.13-5.00	—		
1974	—			150	2.22	0.40-4.51	590	0.98	0.10-3.20	—		
1975	88	6.47	2.45-11.59	159	2.14	0.32-5.49	69	0.81	0.16-1.90	15	0.73	0.15-1.28
1976	50	7.83	4.50-12.10	145	2.05	0.28-4.70	246	0.93	0.11-3.00	50	0.98	0.18-1.70
1977	30	6.97	2.90-9.90	90	1.92	0.48-8.60	35[1]	0.81	0.37-1.60	27	0.60	0.10-1.60
1978	7	6.87	3.93-11.16	40	1.60	0.33-3.50	25	0.65	0.14-1.80	—		
1979	51	5.90	3.06-9.85	60	1.87	0.36-4.98	30	0.81	0.11-1.51	36	0.53	0.11-1.45
1980	16	8.64	3.67-13.09	39	1.82	0.80-3.24	8	0.95	0.33-0.95	—		
1981	18	6.74	3.30-11.00	60	1.23	0.25-4.50	—			—		
1982	—			—			—			—		
1983	—			—			—			15	0.55	0.13-1.90

N = Number of samples
[1]From 1977 on, the Lake St. Clair samples were taken from Tremblay Creek.
Source: Ontario Ministry of the Environment, May 1984.

two other drainage basins, Assiniboine River and Milk River, over the four periods. Although there were no data for the first two periods for two other drainage basins (Gulf of St. Lawrence and Atlantic Coast) the results for the two most recent periods indicate continuing arsenic contamination at levels above the specified limits.

The results for cadmium appear to indicate that it was not until 1980-82 that there was any real decrease in cadmium concentration levels (Table 8.26 and Figure 8.20). The distribution of the number of samples among the various drainage basins in the latest period was, however, quite different; this could account for some of the apparent improvement. There is also an additional difficulty in assessing trends from the data in the 5 μg/L columns because of the different detection limits in the two analytical methods used.

Lead seems to have decreased in most of the drainage basins; the percentage of results exceeding the specified limits over the four periods decreased steadily (Table 8.27 and Figure 8.21). Again, not all basins were sampled in every period, and the distribution of the actual number of samples varied with both the basin and the period — especially in 1980-82.

The number of mercury analyses recorded for the latest period (1980-82) was substantially lower than the number in earlier periods, largely because of the absence of data from Ontario and the prairie provinces (Table 8.28 and Figure 8.22). The overall results indicate a substantial decrease in the percentage of observations above the specified limits.

Mercury in the environment has been the subject of particular attention in several countries, since the discovery that heavy consumption over prolonged periods of fish containing methyl mercury causes irreversible neurological damage in human beings (Minamata disease). Inorganic mercury in water is transferred rapidly to sediments, from which it is released only slowly. It is then gradually converted by enzymatic and bacterial action to methyl mercury which bio-accumulates* in fatty fish tissues. Studies following the discharge of mercury from industrial sources along the Saskatchewan River at Saskatoon led to the establishment of new discharge controls and fish contamination limits (0.5 parts per million) in Canada in the early 1970s. Based on this standard, commercial fisheries on the St. Lawrence and Ottawa Rivers, on Lakes Erie, Huron, Ontario, St. Clair and St. Francis, and along the English-Wabigoon River system were closed in 1970. In 1971, a tuna fishery in the Gulf Coast-Fundy area of Nova Scotia closed after landing 4 600 tonnes of fish the previous year. There have also been a number of closures along the South Indian and Nelson River systems in northern Manitoba because of elevated levels of naturally-occurring mercury. Some closed fisheries have been re-opened for sport fishing when mercury levels have declined. Fish inspection and monitoring programs were established, and some provincial agencies now issue annual guides to anglers reporting levels in

*That is, the higher the organism is in the food chain, the more mercury it accumulates. A fish species that feeds on other predatory species and has high levels of body fat would have the greatest level of mercury.

various species and sizes in different lakes and recreational areas.

Mercury levels in walleye have been monitored widely for some years. In Ontario, data from three different areas were chosen. Two of these, the English-Wabigoon River system and Lake St. Clair, involved known sources of mercury discharge. In the Lake Simcoe area there was no known direct source of mercury discharge. In the case of the English-Wabigoon River system, samples of walleye were taken from a series of four lakes downstream from the point of discharge, with Clay Lake being the closest. Data for the other three lakes were aggregated to give a single series. Data covering the period from 1970 to 1983 are summarized in Table 8.29. Data do not take into account the size or age of the fish. Results from the English-Wabigoon River system show that mercury levels in walleye from Clay Lake are consistently higher than levels in walleye from Ball, Separation and Tetu Lakes. The absence of any evident trend over time in any part of the system, despite marked reductions in mercury discharge from the Dryden plant, is probably attributable to the slow release of inorganic mercury from sediments, its gradual conversion to methyl mercury, and 'natural' contamination. In the case of Lake St. Clair, however, there does appear to be a reduction over time, particularly during the first few years. Here again the residual levels may reflect the combined effect of long-term slow release from sediments and natural sources. The levels recorded in Lake Simcoe samples were generally lower than levels in samples from the other lakes; differences from year to year may simply mean that samples were taken from older, larger fish, whose tissues had accumulated mercury concentrations over time.

Mercury levels in walleye collected from varying numbers of sites throughout Manitoba, Saskatchewan and Alberta between 1970 and 1983 have been aggregated and summarized in Table 8.30. The mean values recorded here are similar to those recorded for Lake Simcoe. These data were collected as part of a fish inspection program that directs its efforts to areas showing higher concentrations. This fact, combined with the variability in numbers of sites and samples from year to year, makes it difficult to draw conclusions about trends.

This brief summary is intended to give a broad picture of mercury contamination in fish. Because of the way data have been aggregated and summarized, one cannot draw conclusions about health risks or the relationship between the levels reported here and the contamination limit of 0.5 ppm established by the Department of National Health and Welfare. Specific guidance for individual sports fishermen concerning species, locations, contamination levels and consumption in some provinces can be obtained from annual publications such as the "Guide to Eating Ontario Sport Fish", published by the Ontario Ministry of Natural Resources.

Table 8.30
Mercury Levels in Walleye, Prairies[1]
(total mercury, ppm wet weight)

	Number of Sites	Number of Samples	Weighted Mean	Range of Individual Values	Range of Mean Values
1970	1	20	0.36	0.19-0.45	
1971	11	1 706	0.45	0.05-1.83	NA
1972	5	215	0.51	0.15-1.40	0.50-0.51
1973	7	1 023	0.48	0.00-2.15	0.48-0.76
1974	8	276	0.47	0.01-2.19	0.39-0.78
1975	7	177	0.52	0.13-1.68	0.45-0.70
1976	10	429	0.69	0.11-2.06	0.53-0.76
1977	13	438	0.71	0.05-3.03	0.47-0.80
1978	129	1 634	0.48	0.03-3.51	0.39-0.50
1979	114	1 352	0.54	0.03-3.29	0.26-0.63
1980	103	1 688	0.75	0.03-3.47	0.11-0.80
1981	142	2 551	0.56	0.01-2.59	0.24-0.69
1982	125	1 205	0.54	0.03-2.99	0.26-0.60
1983	94	1 239	0.61	0.01-4.10	0.24-0.75

[1]Data for Manitoba, Saskatchewan and Alberta combined.
Source: Fisheries and Oceans Canada, Western Region computer file, April 1984.

RADIOACTIVITY FROM ATMOSPHERIC NUCLEAR TESTS

Environmental radioactivity has attracted a great deal of public attention over the years following extensive atmospheric nuclear testing programs and the development (and subsequent malfunction) of a number of nuclear power facilities. Popular concerns relate to real or potential exposure to ionizing radiation and the possible health effects now and in future generations. In fact, exposure to ionizing radiation occurs from natural radioactivity in the soil and building materials and from cosmic radiation from outer space. Human beings have been exposed to background radiation throughout history. Natural background exposures vary appreciably and depend on factors such as altitude and geological conditions.

To put this in perspective, if the annual radiation dose from natural sources is given the value of 1.0, then the equivalent dosage from medical sources (in technologically advanced countries) would be ⅓ (although at high concentrations for very short periods). The dosage from nuclear fall-out (average annual exposure between 1951 and 1976) was equivalent to 0.07 of that from natural sources.

Ionizing radiation is a term used to describe both electromagnetic radiation (X-rays and gamma rays) and particulate radiation (beta particles and alpha particles) emitted in nuclear transformation processes. Such

transformations can take place in the natural process of disintegration of a radioactive element, or when certain elements are subjected to nuclear bombardment by neutrons (e.g., fission of uranium in a nuclear reactor).

The different kinds of ionizing radiation have different properties: alpha particles are easily absorbed, while gamma rays are highly penetrating. Radioactive substances also have different characteristics. The half life (the time needed for a given amount of a substance to lose half its radioactivity) varies widely from seconds to thousands of years, and the type and energy of the emitted radiation are variable as well. The process of nuclear disintegration cannot be altered by physical, chemical or biological means.

Evidence abounds concerning the harmful effects of exposure to excessive amounts of ionizing radiation. The short- and long-term effects of radiation sickness in survivors of the Hiroshima and Nagasaki atomic blasts have been thoroughly documented. The lack of awareness of the dangers of exposure to radiation in the early part of the century, and the consequent failure to provide effective protective measures, have resulted in well documented cases of cancer among industrial and laboratory workers. Controlled animal studies have shown that radiation exposure can cause genetic defects in subsequent generations. Health effects are generally classed as either somatic (occurring in the exposed individual) or genetic (appearing in later generations).

Increasing awareness of these various kinds of effects led to the formation, over 50 years ago, of an international non-governmental body, called the International Commission on Radiological Protection, with a mandate to develop and publish recommendations in this field. The ICRP has issued many reports and made recommendations based on periodic reviews of the most up-to-date information. Standards with respect to levels of exposure that at one time were considered acceptable have frequently been lowered as new data became available. This is a continuing process, and questions are still being raised about the adequacy of current recommendations.

The popular debate about the present and future role of nuclear power has several facets. In addition to the fundamental scientific question about potential exposure and subsequent effects, there are questions of risk relating to the disposal of radioactive wastes and nuclear accidents. Furthermore, there are moral and ethical questions related to the risk of nuclear war and the survival of the biosphere. The environmental effects of a full-scale nuclear exchange are literally incalculable.

For this report, however, the analysis is limited to the levels of contamination in Canada resulting from atmospheric nuclear testing since 1960. The focus here is on northern hemisphere testing, because stratospheric wind movements are such that relatively small amounts of nuclear debris from tests in the southern hemisphere are carried across the equator for deposition in the north. Atmospheric nuclear testing results in the transport of fission products high into the stratosphere, where they are carried around the world by the prevailing winds and gradually returned to earth by meteorological processes. It is often possible to correlate increased ground-level concentrations of nuclear fall-out with atmospheric testing some weeks earlier. Because atmospheric nuclear

Table 8.31
Announced Northern Hemisphere Atmospheric Nuclear Tests >1 000 kt Since 1960

Location	Date	Size (kt)
United States		
Christmas Island 2°N 157°N	2 May 1962	>1 000
Christmas Island 2°N 157°N	10 June 1962	>1 000
Christmas Island 2°N 157°N	27 June 1962	>1 000
Christmas Island 2°N 157°N	30 June 1962	>1 000
Johnston Island 17°N 169°E	9 July 1962	1 400
Christmas Island 2°N 157°W	11 July 1962	>1 000
Johnston Island 17°N 169°E	18 Oct 1962	>1 000
Johnston Island 17°N 169°E	30 Oct 1962	>1 000
Union of Soviet Socialist Republics		
Novaya Zemlya 75°N 55°E	10 Sept 1961	>1 000
Novaya Zemlya 75°N 55°E	12 Sept 1961	>1 000
Novaya Zemlya 75°N 55°E	14 Sept 1961	>1 000
Novaya Zemlya 75°N 55°E	16 Sept 1961	>1 000
Novaya Zemlya 75°N 55°E	18 Sept 1961	>1 000
Novaya Zemlya 75°N 55°E	20 Sept 1961	>1 000
Novaya Zemlya 75°N 55°E	22 Sept 1961	>1 000
Novaya Zemlya 75°N 55°E	2 Oct 1961	>1 000
Novaya Zemlya 75°N 55°E	4 Oct 1961	>1 000
Novaya Zemlya 75°N 55°E	6 Oct 1961	>1 000
Novaya Zemlya 75°N 55°E	30 Oct 1961	58 000
Novaya Zemlya 75°N 55°E	31 Oct 1961	>1 000
Novaya Zemlya 75°N 55°E	4 Nov 1961	>1 000
Novaya Zemlya 75°N 55°E	5 Jul 1962	30 000
Novaya Zemlya 75°N 55°E	20 Jul 1962	>1 000
Novaya Zemlya 75°N 55°E	22 Jul 1962	>1 000
Novaya Zemlya 75°N 55°E	25 Jul 1962	>1 000
Novaya Zemlya 75°N 55°E	27 Jul 1962	>1 000
Novaya Zemlya 75°N 55°E	8 Sept 1962	>1 000
Novaya Zemlya 75°N 55°E	15 Sept 1962	>1 000
Novaya Zemlya 75°N 55°E	16 Sept 1962	>1 000
Novaya Zemlya 75°N 55°E	18 Sept 1962	>1 000
Novaya Zemlya 75°N 55°E	19 Sept 1962	>1 000
Novaya Zemlya 75°N 55°E	21 Sept 1962	>1 000
Novaya Zemlya 75°N 55°E	25 Sept 1962	>1 000
Novaya Zemlya 75°N 55°E	27 Sept 1962	<30 000
Novaya Zemlya 75°N 55°E	22 Oct 1962	>1 000
Novaya Zemlya 75°N 55°E	24 Dec 1962	~20 000
People's Republic of China		
Lop Nor 40°N 90°E	17 June 1967	~3 000
Lop Nor 40°N 90°E	27 Dec 1968	~3 000
Lop Nor 40°N 90°E	29 Sept 1969	~3 000
Lop Nor 40°N 90°E	14 Oct 1970	~3 000
Lop Nor 40°N 90°E	26 June 1973	2 000-3 000
Lop Nor 40°N 90°E	27 June 1973	3 000
Lop Nor 40°N 90°E	17 June 1974	1 000-2 000
Lop Nor 40°N 90°E	Nov 1976	4 000
Lop Nor 40°N 90°E	Oct 1980	1 000

Source: M.W. Carter and A.A. Moghissi, "Three decades of nuclear testing", *Health Physics* 33 (1977): 55-71.
Personal Communication, Dr. E. Veska, Radiation Protection Bureau, Health and Welfare Canada, 1984.

Table 8.32
Radioactive Fall-out Measurements, Surface Air: Gross Beta Radioactivity, Monthly Averages
(millibecquerels per cubic metre)

	Number of Sites	Overall Annual Average	Overall Maximum Monthly Value		Single Site Maximum Monthly Value		
			Month	Value	Site	Month	Value
1960	23	5.0	April	8.0	Ottawa	March	12.0
1961	24	80.0	September	270.3	Thunder Bay	September	695.7
1962	24	113.4	November	200.2	Calgary	November	430.4
1963	24	106.8	May	186.9	Montreal	May	263.6
1964	24	15.0	May	28.4	Saskatoon	May	40.0
1965	24	3.3	June	8.3	Calgary	June	18.4
1966	24	1.7	November	6.7	Windsor	November	20.0
1967	24	3.3	January	25.0	Calgary	January	220.2
1968	24	1.7	March, April, May	3.3	Calgary	May	5.0
1969	24	1.7	May, June, July, August	3.3	Calgary	June	6.7
1970	24	3.3	May, June, July	5.0	Calgary	June, July	10.0
1971	24	3.3	May, June, July	5.0	Regina	June	10.0
1972	24	1.1	January	1.7	Fredericton, Quebec, Montreal	January	3.3
1973	24	0.3	January-December	0.3	St. John's	October	0.8
1974	24	1.0	June	1.7	Winnipeg, Regina	June	4.0
1975	24	0.7	February, March	1.2	Thunder Bay	March	1.7
1976	24	0.3	November	0.8	Saskatoon, Windsor	November	1.5
1977	24	1.0	October	2.2	Regina	October	4.7
1978	25	1.0	March	4.3	Calgary	March	22.5
1979	26	0.5	February	1.1	Whitehorse	February	1.8
1980	27	0.6	January, February	0.7	Resolute	February	1.7
1981	28	2.1	May	4.6	Hamilton	April	9.8
1982	29	0.6	February	0.9	Coral Harbour	February	3.0
1983	29	0.5	January, February	0.7	Edmonton	February	1.6

Detection Limit: 0.1 mBq/m^3. Maximum Acceptable Concentration: 30 000 mBq/m^3
Sampling frequency: daily, 1960-69; weekly, 1970-1983 except for short periods of daily sampling after nuclear tests.
Source: Personal Communication, Dr. E. Veska, Radiation Protection Bureau, Health and Welfare Canada, 1984.

testing is carried out largely for military purposes, only very broad quantitative data have been published.[1] The announced atmospheric nuclear tests taking place in the northern hemisphere since 1960 with an explosive force greater than the equivalent of 1 000 kilotonnes of TNT are summarized in Table 8.31.

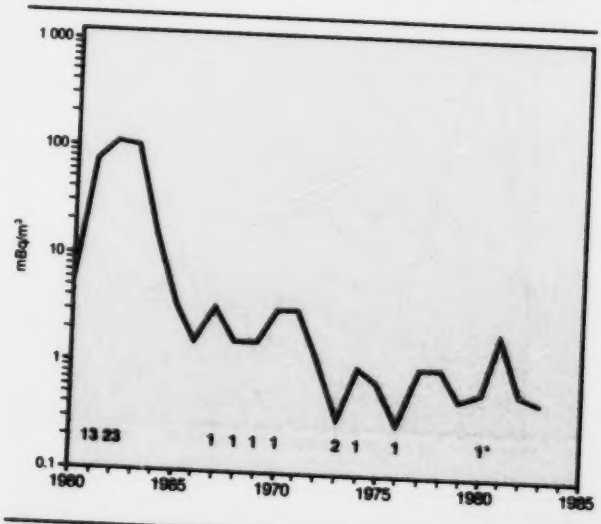
The monitoring program involved collecting samples from a basic network of stations. Samples were analyzed in one laboratory to assure high reproducibility of results; periodic intercalibration studies with laboratories in other countries were conducted; and samples were taken to reflect levels at different stages in the food chain.

The Canadian radioactive fall-out monitoring network sampled air and precipitation at 24 meteorological stations across Canada and in the far north,* as well as fluid milk collected from major dairies serving 16 urban centres across Canada.** Air samples were

*Air and Precipitation Sampling Network: Resolute, Inuvik, Whitehorse, Yellowknife, Coral Harbour, Vancouver, Edmonton, Calgary, Saskatoon, Regina, Fort Churchill, Winnipeg, Thunder Bay, Moosonee, Sault Ste. Marie, Windsor, Toronto, Ottawa, Montreal, Quebec City, Fredericton, Halifax, St. John's, Goose Bay and, more recently, Hay River, Hamilton, Greenwood and Digby.

**Milk Sampling Network: Vancouver, Edmonton, Calgary, Saskatoon, Regina, Thunder Bay, Sault Ste. Marie, Windsor, Toronto, Ottawa, Montreal, Quebec City, Moncton, Halifax and St. John's.

Figure 8.23
Gross Beta Radioactivity in Canadian Air Samples, 1960-1983



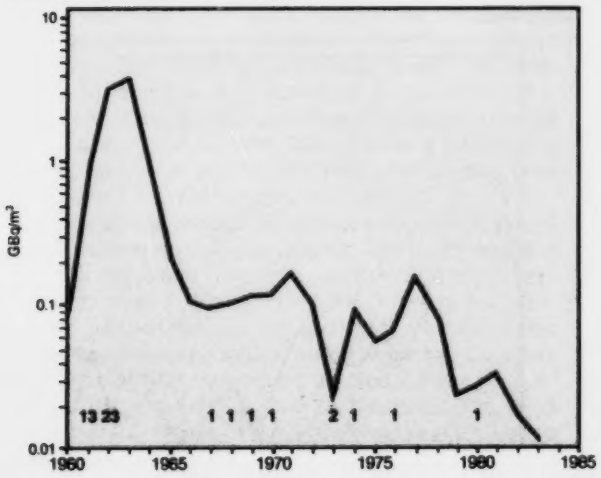
*Numbers indicate the number of announced atmospheric nuclear tests greater than 1000 kilotonnes in the northern hemisphere. See also Figures 8.24 and 8.25.
Source: Table 8.32.

Table 8.33
Radioactive Fall-out Measurements, Precipitation: Gross Beta Radioactivity, Monthly Averages
(gigabecquerels per square kilometre)

	Number of Sites	Overall Annual Average	Overall Maximum Monthly Value		Single Site Maximum Monthly Value		
			Month	Value	Site	Month	Value
1960	24	0.085	May, June	0.159	Calgary	June	0.385
1961	24	0.981	September	3.626	Churchill	September	21.982
1962	24	3.267	November	5.202	Vancouver	November	21.090
1963	24	3.955	June	8.466	Calgary	June	21.893
1964	24	0.939	May	2.216	Thunder Bay	May	6.183
1965	24	0.211	May	0.733	Thunder Bay	May	4.248
1966	24	0.100	May	0.315	Winnipeg	May	2.076
1967	24	0.089	January	0.485	Toronto	January	2.916
1968	24	0.107	June	0.215	Vancouver	January	0.566
1969	24	0.118	July	0.311	Winnipeg	July	0.766
1970	24	0.118	June	0.248	Saskatoon	June	0.692
1971	24	0.167	June	0.451	Thunder Bay	May	1.328
1972	24	0.100	June	0.159	Sault Ste. Marie	June	0.333
1973	24	0.022	August	0.037	Edmonton	August	0.178
1974	24	0.085	May	0.218	Quebec	May	0.981
1975	24	0.056	May	0.096	Ottawa	May	0.329
1976	24	0.067	October	0.300	Sault Ste. Marie	November	2.139
1977	24	0.163	July	0.396	Winnipeg	June	1.602
1978	24	0.089	June	0.167	Windsor	March	0.681
1979	24	0.024	June	0.060	Quebec	June	0.165
1980	24	0.028	August	0.058	Sault Ste. Marie	August	0.160
1981	28	0.033	April-June	0.052	Sault Ste. Marie	April-June	0.109
1982	28	0.017	July-September	0.020	Sault Ste. Marie	April-June	0.076
1983	28	0.012	July-September	0.014	Ottawa	April-June	0.031

Detection Limit: 0.001 GBq/km^2. Maximum Acceptable Concentration: 70 GBq/km^2.
Sampling frequency: monthly, 1960-1980; quarterly, 1981-83.
Source: Personal Communication, Dr. E. Veska, Radiation Protection Bureau, Health and Welfare Canada, 1984.

Figure 8.24
Gross Beta Radioactivity in Canadian Precipitation Samples, 1960-1983



Source: Table 8.33.

collected and analyzed for gross beta radioactivity on a daily basis (just after nuclear atmospheric tests) and weekly when levels of radioactivity decreased. Samples of cumulative rain or snowfall were collected monthly/quarterly and analyzed for gross beta radioactivity to give first indication of actual deposition. Milk samples from different dairies were taken in proportion to their respective sales, and monthly/quarterly composites for each urban centre were analyzed for strontium-90 and cesium-137, two longer-lived fission products that pose concerns for human health. Strontium-90 is chemically like calcium and concentrates in bone tissue; its beta particle emissions could, therefore, irradiate sensitive bone marrow. Cesium-137 is an element that is chemically like potassium and concentrates in muscle and soft tissue. It emits both beta particles and gamma rays and could, therefore, irradiate the whole body, including the reproductive organs.

Surface air monitoring data for 1960 to 1983 are summarized in Table 8.32. Overall annual averages during the early 1960s exceeded 100 millibecquerels per cubic metre (mBq/m^3), but by the late 1970s the annual average rarely exceeded 1.0 mBq/m^3. Some indication of the variability from month to month and by individual station is also shown by listing the overall maximum monthly value and the single site maximum value for each year. For example, in 1960 the

Table 8.34
Radioactive Fall-out Measurements, Milk: Strontium-90, Monthly Averages
(becquerels per litre)

	Number of Sites	Overall Annual Average	Overall Maximum Monthly Value		Single Site Maximum Monthly Value		
			Month	Value	Site	Month	Value
1960	16	0.47	February	0.63	Montreal	February	1.09
1961	16	0.35	July	0.43	Montreal	July	0.75
1962	16	0.80	November	1.33	Fredericton	November	2.59
1963	16	1.31	August	1.95	St. John's	August	3.64
1964	16	1.40	May	1.72	St. John's	August	2.77
1965	16	0.96	May	1.13	St. John's	June	2.00
1966	16	0.66	February	0.79	Thunder Bay	January	1.14
1967	16	0.48	June	0.59	St. John's	July	1.25
1968	16	0.41	July	0.44	St. John's	July	1.27
1969	16	0.36	July	0.47	St. John's	July	1.35
1970	16	0.34	August	0.40	St. John's	August	1.13
1971	16	0.33	July-September	0.38	St. John's	July-September	1.16
1972	16	0.29	July-September	0.30	St. John's	July-September	1.04
1973	16	0.22	April-June	0.23	St. John's	April-June	0.41
1974	16	0.21	July-September	0.23	St. John's	July-September	0.60
1975	16	0.17	July-September	0.19	St. John's	July-September	0.52
1976	16	0.13	April-June	0.17	Sault Ste. Marie	April-June	0.35
1977	16	0.17	July-September	0.20	St. John's	July-September	0.49
1978	16	0.16	July-September	0.19	St. John's	July-September	0.47
1979	16	0.13	October-December	0.14	St. John's	October-December	0.30
1980	16	0.11	January-March	0.12	Moncton	January-March	0.21
1981	16	0.09	July-September	0.12	St. John's	July-September	0.30
1982	16	0.11	July-December	0.16	Edmonton	April-June	0.71
1983	16	0.05	All months	0.05	Moncton	All months	0.10

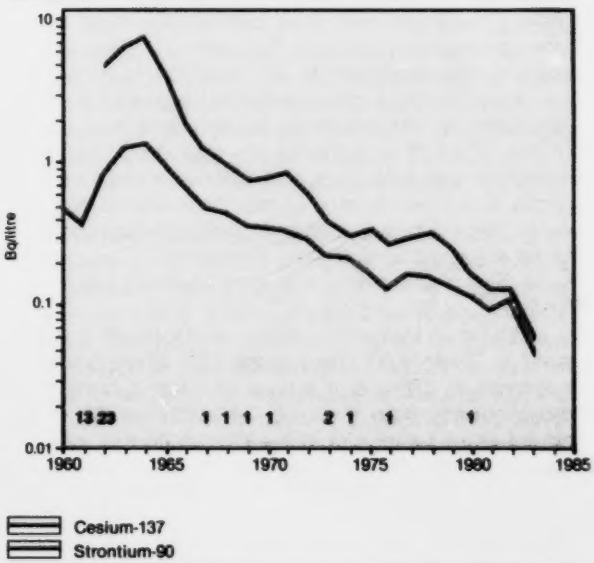
Detection Limit: 0.01 Bq/L. Maximum Acceptable Concentration: 10 Bq/L.
Sampling frequency: monthly, 1960-1970; quarterly, 1970-1983.
Source: Personal Communication, Dr. E. Veska, Dr. B. Tracy, Radiation Protection Bureau, Health and Welfare Canada, 1984, 1985.

annual average for the network of 23 sites was 5.0 mBq/m^3, the highest monthly value for the whole network was 8.0 for the month of April, and the highest single site monthly value was 12.0 for Ottawa, in the month of March. Because the composition of freshly produced fission products changes rapidly with time (as the short-lived components decay), it is difficult to establish permissible levels. It is important, however, to have some way of evaluating the results shown in Table 8.32, and a theoretical maximum acceptable concentration has been calculated. This figure is 30 000 mBq/m^3. Even the highest single station maximum value recorded was less than 700. The overall annual average beta radioactivity in air from 1960 to 1983 is plotted in Figure 8.23. This graph also shows the number of announced northern hemisphere atmospheric nuclear tests larger than 1 000 kilotonnes each year.

Table 8.33 and Figure 8.24 are similar, except that they relate to the results from precipitation sampling. Here again, higher levels are characteristic of the early 1960s and correlate with announced nuclear tests. As with the air samples, levels have decreased greatly since the 1960s. The highest single value from any site in any month was about one-third of the maximum acceptable concentration.

The data for strontium-90 in fluid milk are summarized in Table 8.34 and Figure 8.25. The peak levels

Figure 8.25
Strontium-90 and Cesium-137 in Canadian Milk Samples, 1960-1983



Source: Tables 8.34 and 8.35.

Table 8.35
Radioactive Fall-out Measurements, Milk: Cesium-137, Monthly Averages
(becquerels per litre)

	Number of Sites	Overall Annual Average	Overall Maximum Monthly Value		Single Site Maximum Monthly Value		
			Month	Value	Site	Month	Value
1962	16	4.93	July	7.19	Moncton	July	10.89
1963	16	6.41	August	9.63	Fredericton	August	16.78
1964	16	7.57	January	9.41	Vancouver	January	18.07
1965	16	3.99	February	6.07	Vancouver	February	9.81
1966	16	1.90	May	2.59	St. John's	July	6.19
1967	16	1.20	May	1.56	St. John's	August	4.07
1968	16	0.94	September	1.15	St. John's	August	2.74
1969	16	0.73	July	1.00	St. John's	August	2.26
1970	16	0.78	July	1.04	St. John's	July	2.67
1971	16	0.82	July	1.07	St. John's	July	2.59
1972	16	0.59	January, February	0.78	St. John's	August	1.52
1973	16	0.38	April	0.53	Sault Ste. Marie	March	0.72
1974	16	0.31	August	0.48	St. John's	August	1.15
1975	16	0.35	June	0.50	St. John's	August	1.19
1976	16	0.27	May	0.37	Thunder Bay	May	0.76
1977	16	0.30	August	0.43	St. John's	August	1.03
1978	16	0.33	July	0.41	St. John's	August	1.08
1979	16	0.26	June	0.34	St. John's	July	0.66
1980	16	0.17	March, August	0.21	St. John's	August	0.60
1981	16	0.13	July	0.22	St. John's	August	0.42
1982	16	0.13	April	0.21	Quebec	April	0.52
1983[1]	16	0.06	January-March	0.09	Montreal, Winnipeg	January-March	0.17

Detection Limit: 0.04 Bq/L. Maximum Acceptable Concentration: 50 Bq/L.
Sampling frequency: monthly, 1962-1982; quarterly, 1982-83.
[1]Most quarterly samples after the first quarter of 1983 were below detection limits.
Source: Personal Communication, Dr. E. Veska, Dr. B. Tracy, Radiation Protection Bureau, Health and Welfare Canada, 1984, 1985.

occurred a year or two later than those for the air and precipitation sampling programs, as the strontium-90 had first to be incorporated into the foods consumed by cows. The subsequent decrease also occurred more slowly and with less marked evidence of the later atmospheric tests. In the case of individual substances like strontium-90, it is possible to determine maximum acceptable concentrations much more satisfactorily. The maximum acceptable concentration of strontium-90 in milk for average daily milk consumption was calculated to be 10 becquerels per litre (Bq/L). The determination of maximum acceptable concentrations assumes that an individual would continue to be exposed at that level throughout a whole lifetime. The highest single station monthly value was 3.64 Bq/L at St. John's in August 1963.

The data for cesium-137 in fluid milk are summarized in Table 8.35 and Figure 8.25. The peak level occurred in 1964, and levels decreased somewhat more quickly than they did for strontium-90. Occasional small increases in the overall annual average seem to relate to subsequent nuclear tests. In this case, the maximum acceptable concentration was calculated to be 50 Bq/L, and the single station maximum monthly value was 18.07 Bq/L at Vancouver in January 1964.

These radioactive fall-out measurements have enabled scientists to carry out long-term evaluations of the transport and movement of fine particles in the atmosphere through to incorporation in the food chain. Following the 1963 Nuclear Test Ban Treaty, the contamination levels in the atmosphere and milk gradually declined as a result of radioactive decay processes and absorption into soil, water and plants. Today, radioactive materials from atomic tests are only slightly above detection limits by the most sensitive analytical techniques. This perhaps demonstrates the capacity of the biosphere to absorb atmospheric contamination once the source has been removed.

ASSESSMENT

To what extent have human beings contaminated natural systems? Is the situation becoming worse or improving over time? The answers to these questions provide a complex and far from certain picture.

This is because, first, we are uncertain about whether the picture obtained from available data is representative of (or can be generalized for) the whole Canadian environment.* Second, our knowledge of

*Part of the problem is the lack of experience in developing statistical techniques to measure spatially dispersed phenomena (as opposed to population sampling techniques). Typically, environmental contamination data are obtained from sites (e.g., eggs from herring gull colonies in the Great Lakes) selected for the purpose of detecting contamination rather than through random sampling methods.

the effects of specific contaminants (or their combination) on biota, and about the assimilative capacity (e.g., biodegrability) of the environment, is generally insufficient to evaluate tolerance levels. Third, we seek out and measure only those contaminants we have knowledge of and can detect; thus there is always the probability of the unknown in the assessment process.

Apart from the sheer difficulty of measuring man-made toxic chemicals in the environment, we are also faced with the very short time series (rarely beyond one decade) for trends analysis. This, coupled with the increasing use of chemicals in production processes and the frequent introduction of new chemicals, suggests that we are only at the beginning of establishing an integrated and comprehensive monitoring system for environmental contamination.

The growth in the use of chemicals parallels a heightened potential risk to the environment. On the other hand, with growing experience in control and the development of appropriate technology, we may successfully contain environmental leakage or, in the case where chemicals are applied deliberately, control their levels to tolerable limits.

Notwithstanding these caveats, we can make some preliminary assessments. It was recognized that this report, of necessity, must be selective in its choice of data for analysis. The task was to identify important contaminants without being overwhelmed by a detailed substance-by-substance analysis.*

The data examined were those related to nutrients in water systems; wastewater discharges; acid rain; selected pesticides; selected industrial organic compounds; hazardous wastes and selected inorganic substances; and radioactivity from atmospheric nuclear tests.

The major human contribution to nutrients in water are phosphorus and nitrate/nitrite loadings from municipal wastewater and crop fertilizer/animal waste runoff. The substantial decline in phosphorus levels in the lower Great Lakes during the period between 1970 and 1980 indicates success in the control programs (e.g., expansion and upgrading of municipal waste treatment systems, restrictions on the use of phosphorus in detergents).

Although phosphorus levels in Lakes Erie and St. Clair are still high, they have been reduced from previous levels. Agricultural runoff in the basin, which has the highest per hectare rate of fertilizer application in Canada, probably accounts for the persistence of this problem.

Evidence of a large proportion of water samples containing 0.1 mg/L of phosphorus in some prairie basins (e.g., the Assiniboine River, Lake Winnipeg) suggests that phosphorus loadings remain a problem in this agricultural region.*

The trend analysis in this report of nitrate/nitrite levels provides an uncertain picture because of the inadequacies of comparable samples. However, like phosphorus, nitrogen contamination is a function of the application of fertilizers — and their use has increased greatly in the past decade or so. Surveys in some of the OECD countries have shown a substantial increase in the concentration of nitrogen in both surface water and groundwater, and nitrogen contamination has emerged as a major concern with respect to the quality of potable water.

Although a great deal of money has been allocated to wastewater treatment facilities in recent years, the overall percentage of the population served by such facilities did not change between 1975 and 1985. In fact, for large communities (greater than 100 000 people), about 25 per cent of the population is still not served by wastewater treatment facilities. The absence of such facilities is most pronounced in Quebec, where only about 6 per cent of the population is served. Significant reductions in the quantities of regulated pollutants discharged by the pulp and paper and petroleum refining industries have been recorded, although 100 per cent compliance had not been achieved by 1980, the latest year for which a status report was available.

Acid rain provides a good illustration of the complex interdependence between contaminants, the economy and the environment. Multi-million dollar figures have been placed on the damage caused by this insidious form of contamination. This problem has been cited frequently as the major environmental problem facing eastern North America. Because of the long-range transport of acidic compounds (sulphates and nitrates), the problem in eastern Canada is associated with emission sources in both Canada and the United States. In the United States, coal-powered electrical utilities are the predominant source of SO_2 emissions, whereas non-ferrous smelters are the predominant source in Canada. In both countries, transportation is the major contributor to NO_x emissions.

The capacity to withstand the harmful effects of the deposition of acidic compounds depends, to a large extent, on the amount of buffering capacity in the soil and water. Sulphate deposition has been identified as the major contributing factor to long-term acidification in eastern Canada. Careful scientific studies of ecosystems have documented many of the adverse effects of compounds, including the loss of fish and other aquatic organisms. About 55 per cent of the surface water area in eastern Canada (exclud-

*With integrated information systems, environmental contamination could be analyzed from a more holistic perspective. This could take the form of analysis of production, use and ultimate deposition in the environment linked to stress-response indicators, including those that measure human and ecosystem health. This approach has perhaps progressed furthest in the analysis of acid rain.

*A high level of total phosphorus (0.1 mg/L) has also been found in remote basins, e.g., Yukon River and Pacific North Coast. These levels are derived largely from mineral phosphorus, a form of phosphorus not easily absorbed by plant life.

ing the Great Lakes) is exposed to sulphate deposition at levels greater than 20 kg/ha/y. The majority of agricultural crops in eastern Canada and about 75 per cent of the annual hardwood yield are grown on areas subject to sulphate deposition of more than 20 kg/ha/y.

The use of agricultural pesticides (particularly herbicides) has grown dramatically in recent years. Pesticides are subject to a registration procedure, and the use of some, such as DDT, has been banned. Others are registered for restricted use. Measurements of the concentration of various organic compounds in bird eggs serve as a good indicator of widespread environmental contamination. Levels of DDE (a metabolite of DDT) and dieldrin in herring gull eggs from nesting colonies in Lake Erie and Lake Ontario have been monitored since 1974. For DDE, levels in Lake Ontario were higher than Lake Erie levels, but in both cases a downward trend was reported. For dieldrin, the concentrations were much lower. Little difference between the lakes was observed, and levels have remained relatively constant during the last several years. Levels of the dioxin 2,3,7,8-TCDD in herring gull eggs collected from Lake Ontario showed a marked decrease between 1971 and 1980 but have remained relatively stable in the last several years. An egg sampling program on the east coast involving three species of birds also showed some locational differences but generally a downward trend in DDE levels.

Two other organic compounds that have been subject to regulatory control are PCBs and mirex. They have been monitored in the egg sampling programs; according to the latest results, levels in Lake Ontario and Lake Erie have declined considerably since 1974. Data from the east coast are more difficult to interpret.

The disposal of hazardous wastes has become an increasingly important problem for Canadians. The full extent of this problem is not well documented, but continuing studies suggest that Ontario and Quebec generate about 85 per cent of such wastes. A progress report on active and inactive waste disposal sites has shown that of approximately 5 000 such sites, more than 10 per cent could present a high risk and require further urgent assessment. Spills, accidents and the generation of mine wastes represent other sources of environmental contamination. Many of these contaminants end up in water bodies. Data concerning water basin contamination with arsenic, cadmium, lead and mercury were examined. Generally, the frequency of concentrations above prescribed limits was found to decrease with time in the period between 1971-73 and 1980-82.

Radiation exposure associated with fall-out from atmospheric nuclear tests is small compared with exposure from natural radiation sources. This subject was, however, of considerable public concern in the early 1960s and has been monitored carefully on a regular and systematic basis in Canada since then. The data show marked reductions in radioactivity concentrations in air, precipitation and milk following the cessation of atmospheric nuclear testing.

In summary, although we are learning increasingly to live with, and to control, potentially dangerous chemicals, we are far from understanding all the stresses created by them or the response of biota. The success stories tend to be with respect to those contaminants where cause-effect relationships are well defined, e.g., DDT or atmospheric nuclear radiation. Unfortunately, the prevalence of trace contaminants, the toxicity of many chemicals, and the nature of the interactions among the chemicals are unknown, resulting in a high level of uncertainty in assessing both the scope and the nature of contaminants in the environment.

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INTRODUCTION

For many people, concern about the environment arises from the effects of contamination on their own health or that of their families. Public anxiety is reinforced by news reports on toxic spills and the leaching of chemicals from disposal sites into waterways, the discovery of contaminants in drinking water, and frequent warnings of suspected carcinogens in food, water, air and soil.

There is direct and indirect evidence of an increasing number of toxins in the environment. For instance, contamination of eggs with organic compounds has been blamed for the reproductive failure of certain bird species. Questions have been raised about the effect of these substances on human health. Some incidents cause major alarm to local populations; examples include the discovery of high levels of contaminants in water and biota samples attributed to the Love Canal waste disposal sites and the tragedies of Minamata and Bhopal. Indeed, the subject of toxic chemicals and the environment has become a high priority with governments. The development of protocols for effective international control is currently being considered in such forums as the Organization for Economic Co-operation and Development, the United Nations Environment Program and the World Health Organization.

Awareness of the link between environmental contamination and health arose from many years of experience in the area of occupational health. Many of the chemical contaminants found in the environment today have been hazards of industrial work environments in the past. The history of industrial development shows documented cases of illness and death when employees were exposed for varying periods of time to excessive levels of certain metal or chemical contaminants. Such incidents have led, over the years, to the establishment of occupational exposure guidelines and standards designed to protect the health of workers.

Setting guidelines or standards involves a number of considerations. These include determining the acceptable risk, evaluating the type, rate and length of exposure, and establishing monitoring methods.

Extrapolating from industrial history to the general population is far from easy. First, the population at risk includes the very young and the very old — age groups that are more vulnerable to toxic exposure than the population of working age. Second, the exposure may be much lower and perhaps more constant, e.g., exposure to formaldehyde from urea-formaldehyde insulation. Although the risk for any one individual may be low, the large number of people exposed could show up in the statistical significance of the chance occurrence of ill health in the population at large.*

Laboratory dose-response studies generally use animals as subjects and are based on single contaminants, whereas human exposure under typical circumstances tends to be complex, often involving a number of contaminants at various levels of concentration. We know relatively little about the combined effects of contaminants (including trace elements) or their bio-accumulation over time. In the absence of well documented research, pragmatic interim guidelines have been adopted to protect against presumed risks to the population. For example, relevant occupational health guidelines and laboratory test data on specific substances are often taken as a starting point, but it is customary to apply an additional safety factor, usually 100 or more, to arrive at a guideline for the general population.

In earlier times, public health workers focused their attention on the bacteriological quality of water supplies and foods — still a primary concern in many parts of the world. In technologically advanced countries, however, public health concerns have broadened to include the wide range of chemical contaminants that can find their way into food and drinking water. Surveillance programs and testing for new contaminants are an increasing part of the activities of public health authorities. On occasion, new standards are established and old standards modified as our knowledge of the effects of contaminants on human health expands. The nagging question remains: what are we ingesting today that will be recognized as a carcinogen tomorrow?

This chapter addresses the subject of human exposure to environmental contaminants, especially in air, water and food. Some data on the levels of certain contaminants in human beings are included. It is not yet possible to infer a direct link between environmental conditions and the incidence of morbidity or mortality in any particular community.* A more detailed examination of a specific situation might reveal some such correlation, but general conclusions cannot be drawn from the data here.

EXPOSURE TO AIRBORNE CONTAMINANTS

Air pollution comes from man-made and natural sources. The latter include smoke from forest fires, wind-blown dust and, on occasion, large-scale volcanic eruptions. Man-made sources include fall-out of sulphur dioxide and other chemicals transported great distances in the upper atmosphere. The familiar sources of localized air pollution are motor vehicles,

*Risk in the population at large is calculated on the basis of occurrence, or incidence, per 100 000 people.

*There have, however, been many cases of contaminant incidences and subsequent documentation of ill-health effects. Minamata, Seveso and the 1952 London fog are just some examples of the association of contamination and high-level incidence of mortality/morbidity.

industrial and public utility smokestacks, and domestic chimneys.

Sulphur dioxide, nitrogen oxides, particulate matter, hydrocarbons, and lead are not only hazards to human health but also have adverse effects on animals, agriculture, forest growth and building materials. The particular mix and concentration of air pollutants vary considerably from location to location and from day to day. The most important determinant of air quality at any given time is the combination of weather conditions, intensity of emissions, and location of sources. Air inversions over industrial areas and the downwind effects of major pollution sources are the most dramatic, but more subtle variations can be observed in periods of economic slowdown, or when shifts in lifestyle take place (e.g., increases in the number of wood-burning stoves). Given the identification of sources and the application of control technology, the efforts of public authorities to control air pollution have reaped many dividends in the quality of the air in Canada's urban and industrial environments. When 'control' involved merely raising the height of smokestacks, all we did was exchange local for long-distance air pollution (e.g., acid rain).

Environment Canada has carried out periodic nation-wide inventories of atmospheric emissions of a number of air contaminants. The large number and diversity of sources make it impracticable to conduct emission measurements on each individual source. Assessments are based on responses to questionnaires, supplemented by calculations based on knowledge of the type of industrial process, level of production and fuel consumption. Emission inventory data provide information on quantities distributed by source, type and location of pollution emission.

The 1980 nation-wide emissions inventory data for particulate matter, sulphur oxides, nitrogen oxides and hydrocarbons are summarized in Table 9.1, which gives total emissions for each contaminant as well as the percentage contribution from major categories and major sources. For example, an estimated 1.9 million tonnes of particulate matter were released in 1980, of which 64 per cent came from industrial sources. The most significant sources of sulphur dioxide were primary copper and nickel processing and electrical power utilities. For hydrocarbons, the major contributors were gasoline motor vehicles and various sectors of the petroleum industry. The largest contributors of nitrogen oxides were gasoline motor vehicles, diesel engines, industrial fuel combustion and power utilities.

Estimates of 1982 nation-wide emissions of lead (see Table 8.21) show that gasoline motor vehicles were by far the largest source of lead in the atmosphere. However, the increasing displacement of leaded by unleaded gasoline since the mid-1970s has contributed significantly to decreasing the quantity of lead emissions from this source. Further information can be obtained from the Environment Canada publication, *National Inventory of Sources and Releases of Lead* (EPS 5/HA/3, September 1985).

The federal and provincial governments have collaborated since 1970 in the development of a program to monitor urban air quality in Canada. This program, called the National Air Pollution Surveillance (NAPS) program, established a network of air monitoring instruments in most Canadian cities with populations over 50 000. Measuring instruments are frequently located at sites considered critical for monitoring sources rather than locations representing the average urban population exposure. In some cities, sites are in industrial and residential areas in order to measure the difference in air quality in relation to distance from the source. The network has expanded over the years from 14 cities (43 instruments) in 1970 to 54 cities (400 instruments) in 1984. Measurements are made by various authorities (federal and provincial), and the absence of acceptable internal quality control procedures before 1974 makes comparisons and trend analyses less satisfactory before that date.

Sulphur dioxide (SO_2), nitrogen dioxide (NO_2) and ozone (O_3) are sampled continuously, and values are recorded hourly. The ozone measurement reflects primarily the interaction between hydrocarbons, nitrogen oxides and sunlight, especially during periods of high temperature and relatively stationary air masses. In addition, intermittent measurements (24-hour samples every sixth day) are made of total suspended particulate matter (TSP) and lead. Statistical data on these records are reported annually by Environment Canada; a trend analysis report is published every second year.

The results can be compared with national ambient air quality objectives, which have been agreed to by federal and provincial authorities. Three air quality levels have been established. The *maximum tolerable level* denotes concentrations that pose a substantial risk to public health and require abatement without delay. Maximum tolerable levels are developed for episodic or short-term exposure. These standards are set for hourly (ozone) or daily (SO_2, NO_2 and suspended particulates) readings. Data of this kind are not included in this report.

The *maximum acceptable level* is intended to provide adequate protection against effects on soil, water, vegetation, materials, animals, visibility, and personal comfort and well-being.

The *maximum desirable level* is intended as a long-term goal for air quality and as a basis for an anti-degradation policy in unpolluted areas of the country.

The national annual ambient air quality objectives for SO_2, NO_2, TSP and O_3 are given in Table 9.2. National air quality objectives for lead have not been established. This is largely because inhalation is by no means the only way human beings take in lead; food and water can also be contaminated. It is therefore difficult to determine what proportion of a total permissible lead burden should be related to inhalation.

Table 9.1
Highlights from Nation-wide Emissions Inventory of Air Contaminants, 1980

Contaminant[1]	Total Emissions (millions of tonnes)	Major Contributors by Category		Major Contributors by Source	
		Category	%	Source	% of Category
Particulate Matter	1.9	Industrial Processes	64.0	Mining and rock quarrying	16.6
				Iron ore mining	12.9
				Sulphate pulping	8.7
				Coal industry	8.4
				Iron and steel production	6.3
				Grain handling	5.1
				Sawmills	4.4
				Primary copper & nickel processing	4.1
				Primary aluminum	3.3
		Miscellaneous	12.9	Slash burning	82.3
		Fuel combustion/stationary sources	16.2	Power utilities	47.6
				Fuelwood combustion	28.3
Sulphur Oxides (as SO_2)	4.6	Industrial Processes	67.1	Primary copper & nickel processing	61.0
				Natural gas processing	12.3
				Iron ore mining	5.2
				Tar sands operations	4.8
				Primary lead & zinc products	3.8
		Fuel combustion/stationary sources	29.9	Power utilities	55.6
				Industrial fuel combustion	33.2
				Commercial fuel combustion	6.1
				Residential fuel combustion	4.8
Hydrocarbons	2.0	Industrial Processes	28.9	Petrochemical industry	36.9
				Coal industry	26.9
				Petroleum refining	23.4
		Transportation	40.3	Gasoline motor vehicles	77.3
		Miscellaneous	25.8	Gasoline/diesel marketing	46.1
				Application of surface coatings	27.7
				General solvent use	15.0
Nitrogen Oxides (as NO_2)	1.7	Transportation	62.1	Gasoline motor vehicles	42.1
				Diesel engines	38.7
				Railroads	10.0
		Fuel combustion/stationary sources	33.8	Industrial fuel combustion	45.8
				Power utilities	39.4

[1]Open sources such as agricultural tilling, unpaved roads, etc. contribute significantly to emissions of particulate matter; similarly, forest fires are important contributors to emissions of hydrocarbons and particulate matter. These sources have been excluded here because the focus is on man-made sources that could be important to urban pollution.

Source: Personal Communication, F. Vena, Environmental Protection Service, Environment Canada, 1985.

Table 9.2
National Annual Ambient Air Quality Objectives

Pollutant	Maximum Desirable Concentration	Maximum Acceptable Concentration
Sulphur Dioxide, SO_2	11 ppb	23 ppb
Nitrogen Dioxide, NO_2	32 ppb	53 ppb
Suspended Particulates	60 $\mu g/m^3$	70 $\mu g/m^3$
Ozone, O_3		15 ppb

ppb: parts per billion
$\mu g/m^3$: micrograms per cubic metre
Source: Environment Canada, *National Urban Air Quality Trends in Canada, 1974-1981*, Publication Number EPS-7-AP-14, 1984.

NAPS data have been summarized to show the number of sampling sites, annual means, the 90th percentile values and the station(s) with the highest annual mean for SO_2, NO_2, TSP, O_3 and lead (see Tables 9.3 to 9.7). The data for SO_2, TSP and lead cover the period since 1974, the data for NO_2 are for the period since 1977, and the data for O_3 are for 1979 to 1982.

The 90th percentile is the annual mean where 90 per cent of all mean values would fall below it. Being at the upper end of annual mean readings, this represents the monitoring station located in an area where there are relatively higher air pollutant concentrations. The location of the highest annual mean station is also recorded in these tables. Providing these three figures (average, 90th percentile, and highest reading) is a simple method of dealing with variations from the mean without encumbering readers with statistical techniques of standard deviations or dispersion indices.

The SO_2 data are summarized in Table 9.3 and Figure 9.1. The number of sampling sites has increased, and this would make comparisons with the earlier data suspect; however, a network of Class 1 stations is used to verify trends. A tendency to locate sample sites in areas with suspected high levels of SO_2 could also bias these readings. However, both the annual mean and the 90th percentile level of SO_2 have declined sufficiently with time to suggest a general downward trend. Stations recording the highest annual mean tend to be in the industrialized areas of Ontario and Quebec. The reduction in SO_2 levels is attributed to lower sulphur content in fuels (e.g., substitution of gas for oil), abatement efforts and technical improvements, as well as decreased production in some industrial sectors.

Pollution abatement equipment (on smelters and pulp and paper mills) and raising of industrial stacks most certainly reduced SO_2 readings at the monitoring stations close to these establishments. A countervailing influence is the increased use of coal (which has a higher sulphur content than oil and gas) for generating power. The high stacks of these utilities have, in a sense, resolved the problem of local urban air pollution only to have it return as an acid precipitation problem.

Data concerning suspended particulate concentrations in urban air since 1974 are summarized in Table 9.4 and Figure 9.2. Again, there has been a significant increase in the number of sampling sites. The data suggest a decrease between 1974 and 1975 in both the overall annual mean and the 90th percentile, followed by relatively constant values until 1980, when both values again declined. Factors that influence suspended particulate concentrations are climatic conditions such as temperature, wind and rain. Human activities that contribute to suspended particulates in urban areas include fuel combustion, construction, heavy industry, and transportation.

Data on ambient lead concentrations for the period since 1974 are summarized in Table 9.5 and Figure 9.3. In this case, there has been a steady decrease throughout the entire period in both the annual mean and the 90th percentile value. The increasing use of unleaded gasoline and the regulation of the lead content of gasolines are the main reasons for this steady improvement. Since leaded gasoline accounts for the largest fraction of the lead in urban air, it is not surprising to find that Montreal, Toronto and Vancouver are the stations recording the highest annual means.

Annual ambient NO_2 concentrations since 1977 are summarized in Table 9.6 and Figure 9.4. While there has been a reduction of about 25 per cent in the values shown between 1977 and 1982, the decrease took place largely in the first year or two. Nitric oxides are produced primarily by high-temperature combustion, as in automobile engines and furnaces. Automobile emission controls, along with variations in cold weather and economic activity, probably account for the year-to-year changes. Cities with long periods of cold weather tend to record high annual means (e.g., Calgary, Edmonton).

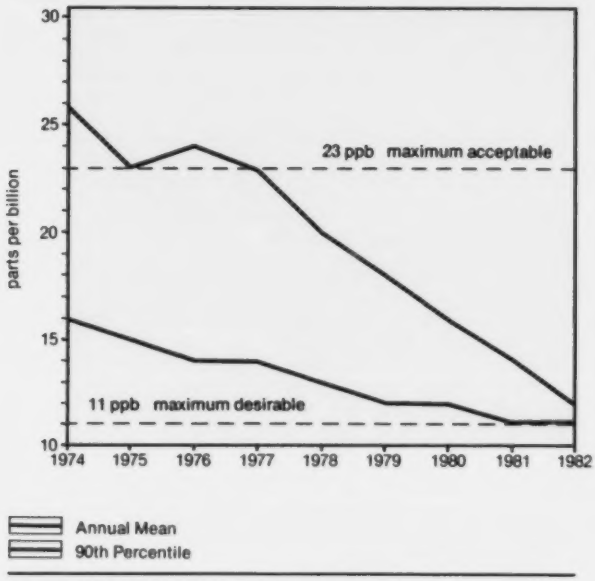
Similar data for O_3 for the period since 1979 are summarized in Table 9.7 and Figure 9.5. Ozone is a secondary pollutant formed principally from the interaction of hydrocarbons and nitrogen oxides under certain meteorological conditions. Internal combustion engines are the principal sources of hydrocarbons and nitrogen oxides. Localities with highest ozone concentrations are in southern British Columbia and the Windsor to Quebec City corridor. Prolonged exposure to high ozone concentrations has been shown to be harmful to the human respiratory system and to plant photosynthesis.

To summarize, the overall annual means for SO_2, NO_2 and total suspended particulates are now at or below the maximum desirable concentration, and 90 per cent of the monitoring sites are recording annual means for SO_2 and NO_2 below the maximum acceptable concentration. The annual mean for O_3, however, did not reach the acceptable air quality objectives during the 1979-1982 period. It should be noted, however, that ozone formation is episodic and that a more meaningful objective would be the 1-hour maximum acceptable level. Lead in urban air continues to decrease, although no standards have been set. Except for ozone, air quality seems to be improving in urban centres. It seems, in general, that exposure of the population to air pollution has decreased during the past decade.

Air quality seems to be improving in cities throughout the industrial world. Nevertheless, a recent OECD report cautioned member countries to give more attention to micro-pollutants (i.e., trace elements of heavy metals, fibres and organic compounds) and to consider actual exposure of the population to various levels of pollutants during normal daily activities.* This suggests the need to consider the effects on

*_The State of the Environment, 1985_ (Paris: OECD, 1985).

Figure 9.1
Nation-wide Annual Ambient SO_2 Concentrations



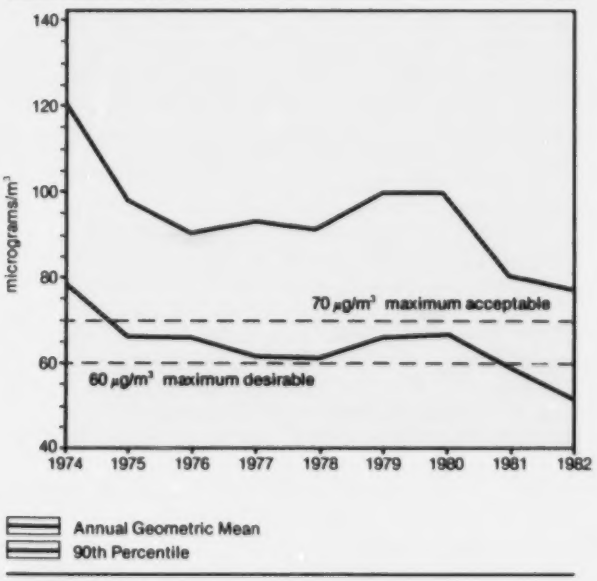
Source: Table 9.3.

Table 9.3
Nation-wide Annual Ambient SO_2 Concentrations, 1974-1982
(parts per billion)

	Number of Sites	National Annual Mean	90th Percentile	Station with highest annual mean
1974	27	16	26	Windsor, 471 University: 33 Sudbury, Ash St.: 33
1975	36	15	23	Montreal, 1212 Drummond: 37
1976	48	14	24	Quebec, Myrand & St. Cyrille: 46
1977	59	14	23	Quebec, Centre de Loisirs: 43
1978	71	13	20	Baie Comeau, 39 av. Marquette: 36
1979	69	12	18	Montreal, Peel & de Maisonneuve: 27
1980	65	12	16	Montreal, Metcalfe & de Maisonneuve: 35
1981	51	11	14	Montreal, Pointe-aux-Trembles: 23
1982	59	11	12	Quebec, 325 Dorchester sud: 23

Source: Environment Canada, "National Air Pollution Surveillance", Annual Summaries, 1975-1983.

Figure 9.2
Nation-wide Annual Ambient Suspended Particulates Concentrations



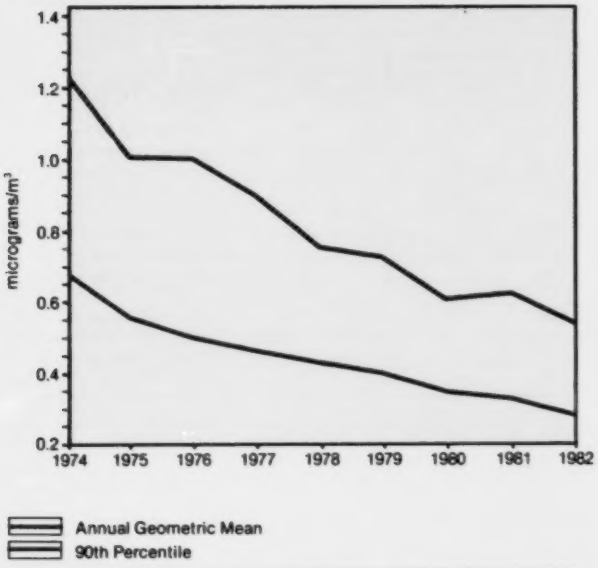
Source: Table 9.4.

Table 9.4
Nation-wide Annual Ambient Suspended Particulates Concentrations, 1974-1982
(micrograms per cubic metre)

	Number of Sites	Annual Geometric Mean	90th Percentile	Station with highest annual geometric mean
1974	59	78.6	121.0	Montreal, Ville Lasalle: 183
1975	59	65.9	98.0	Montreal, Duncan & Decarie: 136
1976	76	65.7	91.0	Edmonton, 100 St. & 102 Ave: 137
1977	83	61.9	93.0	Saskatoon, 4th Ave & 23rd St.: 112
1978	91	61.4	92.0	Shawinigan, Frigon & Laval: 147
1979	96	66.0	99.0	Sydney, Whitney Pier Fire Station: 146
1980	101	66.8	99.0	Calgary, 316-7th Ave.: 159
1981	87	58.6	80.0	Calgary, 316-7th Ave.: 149
1982	93	51.8	77.0	Calgary, 316-7th Ave.: 117

Source: Environment Canada, "National Air Pollution Surveillance", Annual Summaries, 1975-1983.

Figure 9.3
Nation-wide Annual Ambient Lead Concentrations



Source: Table 9.5.

human health not only of ambient air quality, but also of the indoor air to which we are exposed at home and at work.

EXPOSURE TO WATERBORNE CONTAMINANTS

Historically, public health concerns have centred on the bacteriological quality of drinking water supplies. Water treatment is now a well established process, but scarcely a year goes by without some communities having to boil drinking water for periods lasting from a few days to several weeks. These situations may result from a breakdown in a water treatment plant or from agricultural land (e.g., intensive livestock operations) during spring runoff or heavy rainfall.

In most of urban Canada, water is drawn from nearby lakes and rivers, although groundwater is still an important source in many areas, such as Kitchener-Waterloo, some prairie towns and Prince Edward Island. Drilled wells are, of course, the primary source of drinking water for rural populations. Water treatment facilities, serving about 80 per cent of the population, are designed particularly to satisfy bacteriological requirements and often do not remove the organic contaminants that are of increasing concern.* Treatment processes could also contribute to degrading the quality of drinking water by using chemicals excessively.

*The increasing popularity of bottled drinking water, some imported from France, suggests the distaste that many people have for treated water.

Table 9.5
Nation-wide Annual Ambient Lead Concentrations, 1974-1982
(micrograms per cubic metre)

	Number of Sites	Annual Geometric Mean	90th Percentile	Station with highest annual geometric mean
1974	58	0.68	1.22	Montreal, Duncan & Decarie: 3.78
1975	57	0.55	1.00	Montreal, Duncan & Decarie: 2.62
1976	57	0.49	1.00	Montreal, Duncan & Decarie: 2.26
1977	64	0.46	0.89	Toronto, Pharmacy & Hwy 401: 1.94
1978	74	0.42	0.75	Montreal, Peel & de Maisonneuve: 1.51
1979	79	0.39	0.72	Montreal, Duncan & Decarie: 1.36
1980	84	0.34	0.60	Montreal, Duncan & Decarie: 1.35
1981	75	0.32	0.62	Toronto, Evans & Arnold: 1.10
1982	80	0.27	0.53	Montreal, Duncan & Decarie: 0.79

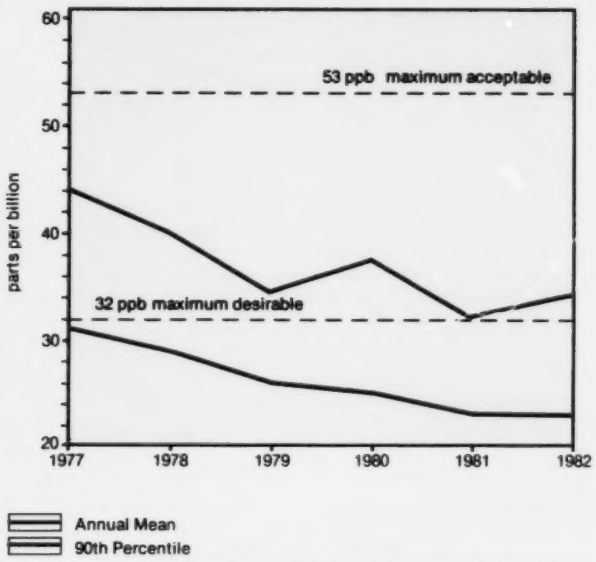
Source: Environment Canada, "National Air Pollution Surveillance", Annual Summaries, 1975-1983.

Standards for an acceptable daily limit of contaminants in drinking water are difficult to determine. The exposure factor is highly variable based on the individual's habits and level of physical activity as well as on climate. Data concerning the provision of water treatment services are summarized in Table 9.8. The data suggest that there was little change in the percentage of the population served by water treatment between 1975 and 1981. For smaller communities (population less than 2 500), only about 40 per cent of the populations surveyed were served by water treatment. For Canada as a whole, about 80 per cent of the population covered by the survey was served by water treatment. The 1981 data are broken down by province and territory in Table 9.9. Of the small communities surveyed in Prince Edward Island, none was served by water treatment. In communities with populations larger than 100 000 surveyed in British Columbia, only about 35 per cent of the population was served by water treatment.*

There is no systematic national monitoring program to measure contaminants in drinking water. Drinking water quality is regarded as a municipal and provincial responsibility, and until relatively recently, there was little evidence that drinking water might constitute an important source of exposure to toxic compounds. Various municipal and provincial drinking water monitoring programs exist, but the data included here relate only to ad hoc surveys conducted at the national level. Two national drinking water surveys, involving 70 municipalities, included measurements of cadmium and lead. The samples were taken over the periods November 1976 to January 1977 and August to September 1977. Some of the variation may reflect differences between winter and summer conditions (e.g., effluent discharge rates, dispersion or

*This low figure is accounted for by the safe water supply in the Vancouver area. These waters are sufficiently pure to require no treatment; at most they are treated to protect water from bacterial contamination while in distribution pipes.

Figure 9.4
Nation-wide Annual Ambient NO_2 Concentrations



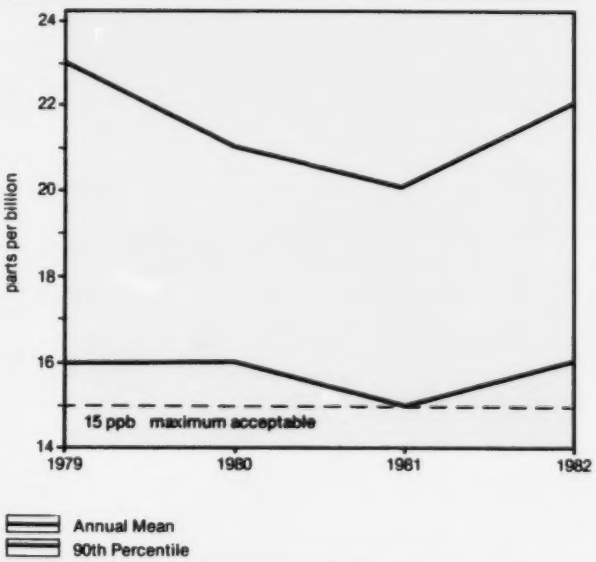
Source: Table 9.6.

Table 9.6
Nation-wide Annual Ambient NO_2 Concentrations, 1977-1982
(parts per billion)

	Number of Sites	Annual Mean	90th Percentile	Station with highest annual mean
1977	27	31	44	Hamilton, Barton & Sanford: 57
1978	33	29	40	Hamilton, Barton & Sanford: 46 Calgary, 620-7th Avenue S.W.: 46
1979	34	26	34	Edmonton, 10255-104th Street: 42
1980	43	25	37	Calgary, 1611-4th St. S.W.: 41
1981	36	23	32	Edmonton, 10255-104th St.: 42
1982	41	23	34	Calgary, 1611-4th St. S.W.: 46

Source: Environment Canada, "National Air Pollution Surveillance Program", Annual Summaries, 1978-1983.

Figure 9.5
Nation-wide Annual Ambient O_3 Concentrations



Source: Table 9.7.

Table 9.7
Nation-wide Annual Ambient O_3 Concentrations, 1979-1982
(parts per billion)

	Number of Sites	Annual Mean	90th Percentile	Station with highest annual mean
1979	39	16	23	Halifax, CFB Shearwater: 28
1980	41	16	21	Cornwall, Memorial Park: 25
1981	35	15	20	Cornwall, Memorial Park: 23
1982	40	16	22	Sarnia, Front St. at CN Tracks: 23

Source: Environment Canada, "National Air Pollution Surveillance", Annual Summaries, 1980-1983.

movement of the contaminants in water at different temperatures, etc.).

Water samples were tested at three levels: (a) raw water; (b) water after treatment; and (c) water from the tap. The data at the last level were analyzed, as they provide the best reflection of actual human exposure. Measurements for cadmium and lead from these surveys are shown in Table 9.10. For cadmium, the median values were close to the detection limit, and no value exceeded the maximum acceptable drinking water guideline of 5 micrograms per litre (μg/L) in either survey. For lead, many of the samples were below the detection limit, but the highest values recorded for three provinces (Saskatchewan, 65 μg/L, Ontario, 46 μg/L, and Newfoundland, 23 μg/L) approached or surpassed the maximum acceptable drinking water guideline of 50 μg/L. This apparent contamination may result from the use of lead pipes and lead-tin solder in the distribution system. These higher

Table 9.8
Population Served by Drinking Water Treatment Systems, 1975 and 1981

		Community Size by Population				
	Date	<2 500	2 501-10 000	10 000-100 000	>100 000	Total
Number of Communities	1975	1 990	516	245	29	2 780
Surveyed	1981	2 377	558	247	30	3 212
Total Population	1975	1 919 965	2 525 645	7 070 792	8 483 888	20 000 290
Covered by Survey	1981	2 145 513	2 775 113	7 159 563	8 843 677	20 923 866
Percentage of Population	1975	38.8	69.8	82.6	93.5	81.4
Served by Water Treatment	1981	41.6	71.1	85.7	93.0	82.4

Source: Environment Canada, "National Inventory of Municipal Waterworks and Wastewater Systems in Canada", 1975, 1981.

Table 9.9
Population Served by Drinking Water Treatment Systems, Canada and the Provinces/Territories, 1981

	Population	British Columbia	Alberta	Saskat-chewan	Manitoba	Ontario	Quebec	New Brunswick
Number of communities surveyed		60	153	116	241	178	1 169	58
Population surveyed	<2 500	79 685	120 293	106 417	113 336	229 196	1 125 976	72 462
% served by water treatment		54.9	83.1	89.9	55.8	80.7	22.8	18.1
Number of communities surveyed		38	45	16	5	143	220	19
Population surveyed	2 501-10 000	214 995	194 248	67 484	74 019	781 911	1 025 255	93 407
% served by water treatment		58.8	95.4	98.4	97.3	70.2	67.9	29.0
Number of communities surveyed	10 001-100 000	34	9	6	3	85	88	7
Population surveyed		1 011 960	244 302	120 401	70 514	2 389 216	2 665 600	243 792
% served by water treatment		70.5	68.9	98.9	100	82.6	95.3	76.6
Number of communities surveyed		3	2	2	1	17	4	
Population surveyed	>100 000	697 000	1 105 637	285 593	577 923	4 179 751	1 869 773	
% served by water treatment		35.4	89.2	99.9	100	99.2	99.8	
Number of communities surveyed		135	209	140	260	423	1 481	84
Population surveyed	Total	2 003 640	1 664 480	579 895	835 792	7 580 074	6 686 604	409 661
% served by water treatment		56.4	86.5	97.7	93.8	90.4	80.2	55.4

	Population	Nova Scotia	Prince Edward Island	Newfound-land	Yukon	Northwest Territories	Canada
Number of communities surveyed		68	21	259	7	47	2 377
Population surveyed	<2 500	59 500	20 148	185 196	4 959	28 345	2 145 513
% served by water treatment		55.3	0	44.0	79.7	75.3	41.6
Number of communities surveyed		27	1	31		3	558
Population surveyed	2 501-10 000	147 825	9 439	150 922		15 608	2 775 113
% served by water treatment		72.5	0	87.7		100	71.1
Number of communities surveyed	10 001-100 000	7	1	6	1		247
Population surveyed		195 849	2 800	173 000	16 929		7 159 563
% served by water treatment		90.1	75.0	82.7	88.6		85.7
Number of communities surveyed		1					30
Population surveyed	>100 000	128 000					8 843 677
% served by water treatment		93.8					93.0
Number of communities surveyed		103	23	296	8	50	3 212
Population surveyed	Total	531 174	57 587	509 118	21 888	43 953	20 923 866
% served by water treatment		82.4	36.5	72.0	86.6	86.1	82.4

Source: Environment Canada, "National Inventory of Municipal Waterworks and Wastewater Systems in Canada", 1981.

Table 9.10
Cadmium and Lead in Drinking Water Supplies[1] across Canada, 1976-77

Contaminant and Period[2]	British Columbia	Alberta	Saskat-chewan	Manitoba	Ontario	Quebec
Cadmium						
November 1976 - January 1977						
Number of Measurements	18	14	10	10	22	40
Median (μg/L)	≤0.01	≤0.01	≤0.01	≤0.01	≤0.01	≤0.01
Range (μg/L)	≤0.01-0.49	≤0.01-0.30	≤0.01-0.01	≤0.01-0.19	≤0.01-0.08	≤0.01-0.17
August 1977 - September 1977						
Number of Measurements	18	9	11	11	52	58
Median (μg/L)	0.02	0.02	0.01	0.04	0.04	0.03
Maximum (μg/L)	0.03	0.05	0.05	0.05	0.09	0.04
Lead						
November 1976 - January 1977						
Number of Measurements	18	14	10	10	22	40
Median (μg/L)	≤1.0	≤1.0	≤1.0	≤1.0	≤1.0	1.0
Range (μg/L)	≤1.0-3.0	≤1.0-1.0	≤1.0-65.0	≤1.0-1.0	≤1.0-46.0	≤1.0-8.0
August 1977 - September 1977						
Number of Measurements	18	9	11	11	52	58
Median (μg/L)	0.3	0.3	0.3	0.3	ND	0.3
Maximum (μg/L)	5.7	0.8	2.6	3.4	ND	3.4

Contaminant and Period	New Brunswick	Nova Scotia	Prince Edward Island	Newfound-land	Yukon	Northwest Territories
Cadmium						
November 1976 - January 1977						
Number of Measurements	8	8	2	6	—[3]	—
Median (μg/L)	≤0.01	≤0.01	≤0.01	0.07	—	—
Range (μg/L)	≤0.01-0.01	≤0.01-0.04		≤0.04-0.28	—	—
August 1977 - September 1977						
Number of Measurements	10	7	6	24	7	7
Median (μg/L)	0.04	0.06	0.01	0.01	0.02	0.03
Maximum (μg/L)	0.05	0.09	0.04	0.09	0.04	0.04
Lead						
November 1976 - January 1977						
Number of Measurements	8	8	2	6	—	—
Median (μg/L)	≤1.0	3.0	1.0	1.5	—	—
Range (μg/L)	≤1.0-4.0	≤1.0-5.0		≤1.0-23.0	—	—
August 1977 - September 1977						
Number of Measurements	10	7	6	24	7	7
Median (μg/L)	ND	ND	0.5	ND	0.3	0.5
Maximum (μg/L)	ND	ND	1.2	ND	0.9	3.6

ND = not detectable.

[1]Water samples taken from water distribution system.

[2]Canadian Drinking Water Guidelines give 5 μg/L as maximum acceptable for cadmium and 50 μg/L for lead.
November 1976 - January 1977 survey covered 70 municipalities; one station was selected for every 200 000 people in each province, representing 38 per cent of the overall Canadian population.
August 1977 - September 1977 survey covered 71 municipalities. Slightly different analytical techniques were used for the two surveys.

[3]No data collected for the winter survey.

Source: J.C. Méranger et al., *Environment Science & Technology* 13 (1979): 707-711.
J.C. Méranger et al., *J. Assoc..Off. Anal. Chem.* 64/3 (1981): 44-53.

Table 9.11
Uranium in Drinking Water Supplies, 1981
(micrograms per litre)

Sampling Site	Average of 12 Monthly Samples	Maximum Monthly Value
Halifax	0.38	0.9 (September)
Ottawa	0.48	1.2 (September)
Port Hope	1.62	2.6 (April)
Elliot Lake[1]	1.29	2.1 (April, June)
Regina	8.99	12.7 (August)
Saskatoon	1.83	3.1 (June)
Whitehorse	1.13	2.1 (April)

[1]No January sample.
Drinking water maximum acceptable guideline: 20 μg/L.
Source: Health and Welfare Canada, "Environmental radioactivity in Canada 1981", Publication Number 83-EHD-102, 1983.

Table 9.12
Tolerances for Trace Elements in Selected Food Items

Substance	Tolerance (parts per million)	Food Item
Arsenic	0.2	Apple juice, cider, wine
	0.1	Beverages as consumed and water in sealed containers other than natural mineral water
	1.0	Edible bone meal
	3.5	Fish protein
	0.1	Fruit juice, except apple juice
Lead	0.5	Apple juice, cider, wine
	0.2	Beverages as consumed and water in sealed containers other than natural mineral water
	10.0	Edible bone meal
	0.15	Evaporated milk, condensed milk and concentrated infant formula
	0.5	Fish protein
	0.2	Fruit juice except apple juice
	0.08	Ready-to-serve infant formula

Source: Food and Drug Regulations, Table 1, Division 15.

Table 9.13
Trace Element Residues in Various Food Types, 1975-1983
(parts per million)

Food Type	Lead			Arsenic			Cadmium		
	N	Mean	Range	N	Mean	Range	N	Mean	Range
Fruits	381	0.086	0.015-1.020	177	0.031	0.010-0.130	140	0.019	0.010-0.090
Vegetables	956	0.048	0.015-0.760	341	0.03	0.02-0.09	293	0.03	0.01-0.23
Meat (red, white)	610	0.075	0.025-0.800	183	0.038	0.010-0.187	131	0.027	0.020-0.170
Meat (kidney, liver)	246	0.123	0.025-0.730	160	0.095	0.010-1.570	32 45	0.36 0.07	0.10-1.29 0.02-0.27
Dairy Products[1]	647	0.09	0.01-1.05	127	0.030	0.010-0.080	121	0.027	0.02-12
Cereal Grain Products	364	0.066	0.01-0.540	64	0.16	0.14-0.32	182	0.059	0.02-0.25
Nuts and Nut Products	62	0.029	0.002-0.084	24	0.03	0.02-0.07	73	0.078	0.02-0.25

N = Sample size
[1]Includes eggs and all types of cheese.
Source: Personal Communication, D.C. Kirkpatrick, Food Directorate, Health and Welfare Canada, 1984.

Table 9.14
PCB Residues in Food, 1975-1983
(parts per million)

Food Type	Number of Samples	Mean	Range
Meat (red, white)	35	0.057[1]	0.018-0.471
Dairy Products[2]	280	0.011	0.001-0.116

[1]Calculated on fat basis.
[2]Includes eggs and all types of cheese.
Source: Personal Communication, D.C. Kirkpatrick, Food Directorate, Health and Welfare Canada, 1984.

concentrations were found in the winter survey. The summer survey concentrations were either not detectable or very low.

These data do not lead to any definite conclusions about differences between winter and summer conditions or about regional differences, other than to suggest a high degree of variability.

The environmental radioactivity monitoring program of Health and Welfare Canada includes measures of uranium concentration in drinking water supplies in several communities across Canada. Uranium occurs naturally and is widely dispersed in the environment, but it occurs in sufficiently high concentrations in some areas (e.g., Elliot Lake, Ontario) to support mining. Uranium refining and fuel fabrication are limited to a few communities, such as Port Hope, Ontario. The natural uranium content of municipal drinking water supplies has been measured monthly for several years, and results for 1981 are shown in Table 9.11. There is considerable variability from one sampling site to another, as well as between individual monthly values. The highest values were observed in the drinking water supply for Regina, which was the only site to draw part of its supply from groundwater sources. All other communities were supplied by surface water sources. All values were below the maximum acceptable level of 20 μg/L. Although natural uranium is slightly radioactive, its chemical properties are considered to constitute a greater health risk and are the basis for the 20 μg/L guideline level.

EXPOSURE TO FOOD CONTAMINANTS

Food has long been recognized as a source of human exposure to potentially toxic chemicals. Some substances, such as lead, cadmium, and arsenic, occur naturally in the earth's crust, and low background levels can be found in virtually all foods. In addition, food can become contaminated through adulteration, industrial processes and environmental pollution. The use of lead-soldered cans may result in elevated lead levels in canned foods, while the smoking of meats and fish can result in the formation of polyaromatic hydrocarbons, which are considered harmful. Nitrates, an additive in processed meats, have also caused concern, because their derivatives, nitrosamines, are highly carcinogenic.

Assessing the health significance of chemical contaminants in food is a difficult task. Many factors must be considered, including the toxicity of the contaminant, the quantity of contaminant in the food, and the potential intake of the contaminant from all sources. The Health Protection Branch of Health and Welfare Canada has established a number of regulations under the *Food and Drug Act* specifying maximum permissible levels of chemicals/contaminants in foods. The tolerance levels for arsenic and lead in various food items are listed in Table 9.12. Guidelines have also been established for a number of man-made chemical contaminants, including PCBs and the dioxin 2,3,7,8-TCDD. Health and Welfare Canada also maintains active research programs on the toxic effects of contaminants (including lead and PCBs) and on the development of sensitive analytical methods to determine the level of contaminants in foods. A summary of measurements of lead, arsenic and cadmium residues in various food types is given in Table 9.13. Data cover the period 1973-1983, and the table shows the number of samples, the mean value and the range of values for each food type.

Similar data for PCB residues in meat and dairy products for the same period are given in Table 9.14. The mean values are generally very low and are not considered harmful to consumers.

Monitoring individual food items to identify commodities with significantly higher contamination levels and to follow trends over time does not necessarily indicate the amount of contaminants actually being consumed. To obtain a better idea of the actual intake for a typical consumer, a series of total diet studies has been made.

The first step was to determine what types and quantities of food constitute a representative Canadian diet. This was based on market figures for food quantities bought and sold and are for the population as a whole, ignoring such factors as personal likes or dislikes, special diets, or changes in eating habits associated with age. The food items were grouped into 12 food composite groups (e.g., milk and dairy products; meat, fish and poultry; cereals; potatoes), and the amount of each group consumed per day was calculated. Food samples were purchased once each calendar quarter at different supermarkets. Composites were analyzed for heavy metals and pesticides, and the results were averaged to obtain an annual figure. This was multiplied by the group's proportional contribution to the total diet to obtain the average daily intake per person.

These studies spanned the period between 1969 and 1978. From 1969 to 1973, the averages reflected the total diet in individual cities (Ottawa-Hull, Vancouver, Halifax, Winnipeg and Toronto). In 1974, samples from a number of cities were analyzed for DDT and dieldrin to reflect a single average daily intake for the country as a whole. For the period April 1976 to January 1978, sampling for these pesticide residues was done at two-month intervals in Halifax, Montreal, Toronto, Winnipeg and Vancouver, and the results were evaluated to give a typical average daily intake during that period.

The data from these studies are summarized in Table 9.15. The information provides data on residues of selected contaminants in representative diets. Differences in levels at various places and times might only represent variations in sampling and analytical techniques, although the DDT and dieldrin data (1969-1978) seem to suggest a decline. Guidelines published by the United Nations Food and Agriculture Organization and the World Health Organization (FAO/WHO)

Table 9.15
Selected Contaminants in Total Diet Samples, 1969-1978

Place/Period	Residue in Representative Canadian Diet (micrograms/person/day)					
	Arsenic	Cadmium	Lead	Mercury	DDT	Dieldrin
Ottawa-Hull 1969	95	80	106	10	18.9	4.0
Vancouver 1970	30	67	128	16	7.4	1.2
Halifax 1971	30	67	148	10	11.5	2.3
Winnipeg 1972	35	52	77	10	4.8	1.5
Toronto 1973	35				4.1	1.8
Canada 1974					1.6	0.7
Canada 1976-78					0.8	0.2
FAO/WHO provisional tolerable daily intakes	140	60-70	430	45		
WHO acceptable daily intake					250	5

Source: D.C. Smith, "Pesticide Residues in the Total Diet in Canada", *Pesticide Science* (1971): 92-5.
D.C. Smith et al., "Pesticide Residues in the Total Diet in Canada II", *Pesticide Science* (1972): 207-10.
D.C. Smith et al., "Pesticide Residues in the Total Diet in Canada III", *Pesticide Science* (1973): 211-14.
D.C. Smith et al., "Pesticide Residues in the Total Diet in Canada IV", *Pesticide Science* (1975): 75-82.
H.A. McLeod et al., "Pesticide Residues in the Total Diet in Canada V 1976-78", *Journal of Food Safety* (1980): 141-64.
J.C. Méranger and D.C. Smith, "The Heavy Metal Content of a Typical Canadian Diet", *Canadian Journal of Public Health* (1972): 53-57.
D.C. Kirkpatrick and D.E. Coffin, "The Trace Metal Content of Representative Canadian Diets in 1970 and 1971", *Journal of the Institute of Food Science Technology* (1974): 56-58.
D.C. Kirkpatrick, "The Trace Metal Content of a Representative Canadian Diet in 1972", *Canadian Journal of Public Health* (1977): 162-4.

Table 9.16
Selected Organic Compound Residues in Adipose Tissue of Canadians, 1969, 1972 and 1976

Compound	Dates	Number of Samples	Micrograms per gram wet weight	
			Mean	Range
ΣDDT	1969	221	4.543	0.18-18.71
	1972	172	2.571	0.875-18.522
	1976	99	2.064	0.055-12.395
Dieldrin	1969	221	0.122	0.02-0.46
	1972	172	0.069	0.001-0.353
	1976	99	0.049	0.003-0.211
PCB (as arochlor 1260)	1969[1]			
	1972	172	0.907	0.106-6.603
	1976	99	0.944	0.040-6.801

[1]No analysis.
Source: W.R. Ritcey et al., "Organochlorine insecticide residues in human adipose tissue of Canadians", *Canadian Journal of Public Health* 64 (1973): 380-386.
J. Mes et al., "PCB and organochlorine pesticide residues in adipose tissue of Canadians", *Bull. Environ. Contam. Toxicol.* 17 (1977): 196-203.
J. Mes et al., "PCB and other chlorinated hydrocarbon residues in adipose tissue of Canadians", *Bull. Environ. Contam. Toxicol.* 28 (1982): 97-104.

on tolerable limits are included to provide a basis for assessing the relative significance of these figures. An individual's actual intake of contaminants would likely vary greatly, depending on dietary habits, seasonal variations, the location of the food source, and the purely chance factor of inadvertent contamination.

The arsenic figures are relatively constant in both time and location, except for the high 1969 figure for Ottawa. Winnipeg shows the lowest concentrations of cadmium and lead. Although the estimated potential intake of cadmium appears to be very close to the FAO/WHO provisional tolerable daily intake, it must be noted that these data may be overestimates because of the limits of detection (lowest detectable concentration). This limit was assumed to be the amount of cadmium present when none of this substance could be detected. Recent information derived from more sensitive assays suggests that the earlier figures may be as much as 10 times too high. Mercury levels do not seem to exhibit a time trend, but the level for Vancouver is somewhat higher than the others.

The food groups that were found to contribute most to the daily intake of cadmium were milk and dairy products, meat, fish and poultry, potatoes and cereals — a fact that probably reflects the large contribution of these food groups to total food intake. Fish and poultry were found to contribute the most mercury, and fish is probably the largest single source. In the case of lead, a number of food groups were involved. In two cities (Ottawa and Halifax) fruits were

Table 9.17
Regional Distribution of Selected Organic Compound Residues in Adipose Tissue of Canadians, 1969, 1972 and 1976
(micrograms per gram wet weight)

		British Columbia & Alberta		Saskatchewan & Manitoba		Ontario		Quebec		Atlantic Provinces	
Compound	Date	Number of Samples	Mean	Number of Samples	Mean	Number of Samples	Mean	Number of Samples	Mean	Number of Samples	Mean
ΣDDT	1969	33	3.671	20	4.981	90	4.826	53	4.584	25	4.063
	1972	27	3.343	22	2.128	57	2.422	50	2.541	16	2.518
	1976	27	2.118	15	2.631	6	1.790	39	2.100	10	1.100
Dieldrin	1969	33	0.130	20	0.125	90	0.127	53	0.108	25	0.119
	1972	27	0.070	22	0.053	57	0.085	50	0.060	16	0.064
	1976	27	0.045	15	0.056	6	0.049	39	0.053	10	0.036
PCB (as arochlor 1260)	1969[1]										
	1972	27	0.898	22	0.499	57	1.070	50	0.969	16	0.727
	1976	27	0.947	15	0.779	6	1.791	39	0.890	10	0.803

[1]No analysis.

Source: W.R. Ritcey et al., "Organochlorine insecticide residues in human adipose tissue of Canadians", *Canadian Journal of Public Health* 64 (1973): 380-386.
J. Mes et al., "PCB and organochlorine pesticide residues in adipose tissue of Canadians", *Bull. Environ. Contam. Toxicol.* 17 (1977): 196-203.
J. Mes et al., "PCB and other chlorinated hydrocarbon residues in adipose tissue of Canadians", *Bull. Environ. Contam. Toxicol.* 28 (1982): 97-104.

by far the largest contributor. This has been attributed to the use, since discontinued, of lead arsenate sprays.

Although the potential daily intake of lead, arsenic and mercury as determined in these studies is well below the FAO/WHO provisional tolerable daily intake, it must be remembered that these data represent an average intake for the population as a whole. Certain segments of the population (e.g., children) may have greater intakes relative to their body weight as well as greater sensitivities to the toxic effects of certain contaminants.

CONTAMINANTS IN HUMAN BEINGS

Measurements of contaminants in air, water or food, although useful indicators of potential exposure, do not measure the actual exposure of human beings as they breathe, drink and eat. Calculation of risk is dependent on such factors as the rate and length of exposure, the chemical form of the contaminant, body weight, physiological characteristics, and clinical sensitivity — all of which vary from individual to individual and with age and sex. Measurement of contaminants in the human body does provide a direct indicator of bio-accumulation.

Many organic compounds tend to concentrate in adipose (fatty) tissues. Monitoring for these substances is frequently based on samples taken at autopsy. Time series data on contaminants in human tissues are necessarily extremely limited. Two programs involving a time series of measurements of DDT, dieldrin and PCBs in adipose tissue have been examined. One program involved autopsy samples from accident victims in various centres across Canada in 1969, 1972 and 1976. The other involved autopsy samples taken in hospitals in Ontario between 1971 and 1981. In this latter series, samples for the period up to 1974 came from hospitals throughout Ontario, while the samples after that date came primarily from London, Ontario.

The results from the first program, which assayed levels of ΣDDT (DDT and its various derivatives), dieldrin and PCB (as arochlor 1260) are summarized in Table 9.16. The data show a pronounced downward trend in levels for both ΣDDT and dieldrin over the period 1969 to 1976. There were no PCB data for 1969, and the PCB data for 1972 and 1976 do not seem to show a decline — the mean value in 1976 was higher than in 1972 and the range of values was wider. The regional distribution data are summarized in Table 9.17. Each region shows a downward trend for both ΣDDT and dieldrin, although the rate of decrease for ΣDDT seems to be slightly greater in Ontario and the Atlantic region. There does not appear to be any consistent regional difference in actual levels. Four of the five regions showed increased mean values for PCBs in 1976 by comparison with 1972. Although the difference was less pronounced in 1972, the levels in Ontario in 1976 were clearly higher than in the other regions.

Table 9.18
Selected Organic Compound Residues in Adipose Tissue of Ontario Residents, 1971-1981

Period	Number of Samples	Mean (micrograms per gram wet weight) DDT	Dieldrin	PCB
1971-72[1]	282	5.67	0.13	2.50
1973-74[1]	129	3.69	0.09	2.30
1976-77[2]	125	5.13	0.04	2.21
1978-79[2]	111	6.30	0.10	2.32
1980-81[2]	125	4.60	0.11	1.91

[1]M. Holdrinet et al., "Organochlorine residues in human adipose tissue and milk from Ontario residents, 1969-1974", *Canadian Journal of Public Health* 68: 74-80.

[2]R. Frank et al., "Organochlorine residues in human adipose tissues, blood and milk from Ontario residents, 1976-1982" (in preparation).

The national data presented in Tables 9.16 and 9.17 are not borne out by the Ontario data presented in Table 9.18. The latter examines five two-year groupings of data. (There are no 1975 figures.) These results do not bear out the downward trend suggested by the national figures for ΣDDT and dieldrin. Given that both DDT and dieldrin were banned in the early 1970s, recent levels may reflect the persistent nature of these residues in human tissues. It is also interesting to note that the Ontario data for ΣDDT show values approximately twice the national mean, a fact that was not evident in the regional analysis of the national data. The range of individual values in all of these measurements was sufficiently large to throw doubt on the significance of the 'mean value', especially as it concerns comparisons over time. The one certain element, based on these and other studies, is that organic compounds and heavy metals continue to be detected in human tissues. There is, as yet, no clear understanding of the tolerance limits or the risk factors involved in their accumulation in human tissues.

ASSESSMENT

To what extent do contaminants in the environment affect human health? Is the situation worsening or improving? That the state of human health is affected by contaminated air, water and food has been known since humankind has observed the relationship between sickness and the environment.*

Today we are concerned about the apparent increase in the level of exposure to chemicals suspected of being carcinogens or mutagens and affecting the general state of human health and well-being. Health statistics, though plentiful, are rarely in a form that allows for correlation of data on exposure with data on ill health.

The most generalized indicator of health is longevity. Statistics on life expectancy in Canada have shown a steady upward trend, indicating that, on the whole, we are healthier today than we were in the past. This observation should be tempered, however, by the realization that our capacity to keep people alive, rather than any actual improvement in health, may account for some of these extra years.

State of health analysis is based, for the most part, on mortality and morbidity statistics (the latter being largely hospital data and data on reportable diseases*). Data to describe the more subtle aspects of health are lacking. Exposure to low levels of contaminants may show up in non-specific symptoms, allergic reactions, or in the context of substantial time lags between exposure and effect. To obtain the latter correlation requires health histories linked to location and/or workplace.

In this report we have assessed the effects of contaminants on human health by indirect evidence (e.g., exposure to urban air, drinking water or food) and direct evidence of contaminants found in human tissues. The most informative approach to assessing the relationship between human health and contaminants is through analysis of epidemiological data. The best available data are those that link cause of death with last place of residence (i.e., the address of the deceased). However, these data say nothing about the all-important life history or even the length of stay in the community of last residence.

Urban air pollution in Canada has declined. In the areas sampled, mean values for SO_2, NO_2 and suspended particulates are now at or below air quality objectives. The efforts of governments to curb emissions of these pollutants have resulted in measurable decreases, but the recent economic recession may also have played a part in improving urban air quality.

Eighty per cent of Canadians are provided with treated drinking water. Data on contaminants in drinking water are limited; nonetheless, where tests have been made for heavy metals, lead, cadmium and uranium, levels were generally low and well within the health risk standards set by public health authorities.

Data from food monitoring programs carried out by Health and Welfare Canada show very low average levels of arsenic, cadmium, lead and PCBs in various food groups. Some individual samples occasionally show levels above tolerance standards. Measurements in total diet samples also show levels of DDT and dieldrin that are well below international standards and guidelines for daily intake. On average, contaminants found in food are not at levels considered to be harm-

*Complaints in Elizabethan London about the unhealthy air produced by burning 'sea coal' are but one of the many historical observations of the relationship between contaminants and human health.

*Hospital morbidity data are influenced by techniques of treatment, and change in rates may merely reflect this fact rather than the incidence among the population at large. Similarly, reportable diseases are prescribed by law and are confined to those considered infectious.

ful to human health and are usually well within the specifications of public health authorities.

Contaminants in human tissues in one survey indicate a downward trend in levels of DDT and dieldrin, both nationally and regionally, between 1969 and 1976. PCBs, however, showed a slightly higher national mean level in 1976 than in 1972, and a wider range of values. Data from an Ontario monitoring program, however, did not bear out either the downward trend for DDT and dieldrin or the increase in PCBs. These data have been included in this report as direct evidence of human contamination, but the samples available are clearly too small to draw conclusions that are as statistically significant.

Data on the causes of death do not yet permit correlation between contaminant exposure and the cause of death for the general population. The only well documented cases in Canada of cause of death from contamination are those associated with the work environment, eating, drinking and smoking habits. In other countries, however, there are studies that have correlated cause of death with known pollution incidents, e.g., the London fog of 1952 and mercury and cadmium exposure in Japan.

Mortality is of course an extreme event; the general experience of ill health is typically more subtle — non-specific symptoms such as fatigue, susceptibility to allergies, and nervous disorders. Data in this area are lacking, although these symptoms are the most likely response to chronic low-level contaminant exposure. We can only speculate about whether the increased popular awareness of the potential dangers of environmental contaminants in the home, at work, and in the ambient outdoor environment is the best, if somewhat unscientific, indicator of the effect of these substances on our general state of health.

10

Legislation and Expenditures

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INTRODUCTION

Canada is a democratic society with a federal government operating in a mixed economy. As a result, control of resources, their uses, and their by-products is widely dispersed between the different levels of government and the private sector.

The *Constitution Act*, which sets the ground rules for interaction between the federal and provincial governments, does not explicitly mention management of the environment. Rather, it assigns exclusive or joint authority to legislate in areas affecting the environment to the different levels of government. Section 91 of the *Constitution Act, 1867* grants the federal Parliament exclusive powers to legislate in some specific environment-related areas: navigation and shipping; seacoast and inland fisheries; Indian lands; federal property; taxation and the spending of its own revenues; statistics; criminal law; federal works and undertakings; and interprovincial and international trade. Section 91 also grants Parliament general emergency and other powers not specifically assigned to the provinces under the peace, order and good government clause.

By virtue of the role of the federal level of government in international affairs, that level of government has acquired plenary legislative authority in the seas off Canada as international law has evolved to extend Canadian jurisdiction to these areas.

Section 92 of the *Constitution Act, 1867* gives exclusive legislative authority to the provincial legislatures in essentially local matters, many of which can bear on the environment: the management of most public lands and forests and the natural resources therein; regulation of local works and undertakings, including mining and manufacturing; direct taxation within the province; the power to spend revenues for provincial purposes; property and civil rights; and all matters of a local or private nature in the province. Section 109 vests ownership of all lands, mines and minerals in a province in the provincial government. The *Constitution Act, 1982* added section 92A, which gives the provinces the right to make laws in relation to non-renewable resources, forestry and electrical energy. Section 95 vests concurrent powers to legislate in relation to agriculture in the federal and provincial legislatures.

As a result of the constitutional division of powers and subsequent judicial decisions, provincial legislatures have considerable legal control over and exert greater influence on the actual regulation and management of environmental matters, although the federal government's authority is not trivial. Effective public sector management of the environment, especially on a national basis, therefore requires close co-operation between the different levels of government. It is worth noting that territorial governments also have legislative authority relating to environmental matters in a number of limited areas; examples are wildlife management and territorial parks.

FEDERAL GOVERNMENT ACTIVITIES IN ENVIRONMENTAL MATTERS

Objectives

Given provincial powers in environmental legislation and management, the federal government's responsibilities are limited to

- administering the environmental laws that fall within its legislative mandate;
- establishing national standards for adoption and enforcement by the provincial governments;
- providing scientific and statistical support and information to federal departments and agencies, to provincial governments, to the private sector, and to the general public;
- encouraging uniformity in resource management by provinces and the private sector; and
- providing financial assistance to provincial programs through various cost-sharing arrangements, and to private sector programs through grants and contributions.

Organization and Legislation

The federal *Government Organization Act* (1979) vests the federal Minister of the Environment with residual responsibilities for all environmental matters over which the Parliament of Canada has jurisdiction but that have not been assigned by law to any other federal department, board or agency. Included in the federal environment minister's portfolio are matters related to the preservation and enhancement of the quality of the natural environment, renewable resources, water and meteorology. The minister is also responsible for protecting nationally significant natural and historical heritage sites; for enforcing those rules and regulations of the International Joint Commission that relate to environmental enhancement; for assuring the co-ordination of the federal government's environmental policies and programs; and for co-ordinating federal-provincial co-operative environmental efforts.

In carrying out this mandate, the minister

1. initiates, recommends, undertakes and co-ordinates programs to promote objectives or standards relating to environmental quality and pollution control;
2. ensures that significant new federal projects are assessed for adverse environmental impact; and
3. provides information to the public.

Federal responsibility for environmental matters lies not only with the Minister of the Environment, however, but also with a number of other ministers.

The Minister of Indian Affairs and Northern Development, for example, is charged with significant environmental responsibilities. Most of the Canadian north is federal Crown land. Environmental factors affect the viability of the renewable resources upon which the traditional lifestyles of Native people

depend. The department's Renewable Resources and Northern Environment Branch is responsible for carrying out most of the minister's environmental functions in the north and the Arctic offshore, including the management of land, water and forests and the development and protection of environmental quality.

Responsibility for the federal role in agriculture and forestry is vested in the Minister of Agriculture. In addition to a mandate encompassing all aspects of the production, research, processing and marketing of crops and livestock (much of which might be considered environment-related), the minister is specifically responsible for federal regulation of pesticides and fertilizers, which are of critical environmental concern. In 1984, federal responsibility for forestry was transferred from the Minister of the Environment to a Minister of State for Forestry within the Department of Agriculture.

The Minister of Fisheries and Oceans has primary responsibility for marine and freshwater fisheries and the protection of aquatic environments. Although the federal government retains constitutional authority, operational responsibility for fisheries resources management has been transferred to some degree to provincial governments. Ontario, Manitoba, Saskatchewan and Alberta have been given full administrative responsibility for fisheries. The British Columbia government is responsible for freshwater fisheries only. In Quebec, the province is responsible for all species of fish that do not at one time or another live in salt water. Every province is responsible for issuing freshwater sport fishing licences. Federal fisheries officers deal with international fisheries conventions and agreements.

Federal ministries responsible for other environmental activities include Transport, Health and Welfare, Energy, Mines and Resources, Public Works, Regional Industrial Expansion, Communications, and Justice.

A summary listing of federal environment-related legislation is provided in Table 10.1. The date shows the year of promulgation of the statute or its incorporation into the Revised Statutes. Where a second date appears, it indicates the year of the most recent amendment.

International Conventions and Treaties

As part of its commitment to improving environmental quality and resource conservation and management in the country and throughout the world, Canada has entered into a broad range of bilateral or international treaties and conventions as well as more informal arrangements. A detailed listing of multilateral environment-related agreements to which Canada is a party or in which Canada maintains a continuing interest is given in Table 10.2.

Table 10.1
Federal Environment-related Legislation

Government Organization Act 1970 1979
Canadian Environmental Week Act 1970
Income Tax Act 1966, 1977
National Museums Act 1967
Criminal Code 1970, 1972
Motor Vehicle Safety Act 1970, 1980
Weather Modification Information Act 1970, 1974
Clean Air Act 1971, 1985
Boundary Waters Treaty 1909
International River Improvements Act 1955
Canada Water Act 1970, 1985
Arctic Waters Pollution Prevention Act 1970
Northern Inland Waters Act 1970, 1985
Canada Shipping Act 1970, 1985
Navigable Waters Protection Act 1970
National Energy Board Act 1970
Oil and Gas Production & Conservation Act 1968
National Housing Act 1970
National Battlefields at Quebec Act 1907, 1953
National Parks Act 1930, 1985
Waterton Glacier International Peace Park Act 1932
Historic Sites and Monuments Act 1953
Newfoundland National Park 1955
Territorial Lands Act 1970, 1972
Canada Land Surveys Act 1970
Indian Act 1970, 1979
Northern Pipeline Act 1978, 1981
Atomic Energy Control Act 1946, 1976
Food and Drugs Act 1954, 1985
Hazardous Products Act 1969, 1983
Radiation Emitting Devices Act 1970, 1982
Railway Act 1970, 1978
National Transportation Act 1970, 1978
Nuclear Liability Act 1970
Pest Control Products Act 1972, 1985
Environmental Contaminants Act 1975, 1985
Ocean Dumping Control Act 1975
Transportation of Dangerous Goods Act 1980
Canada Oil and Gas Act 1982
Aeronautics Act 1970
Fertilizers Act 1957, 1970
Agriculture and Rural Development Act 1966
Prairie Farm Rehabilitation Act 1970, 1983
Pesticide Residue Compensation Act 1970
Animal Disease and Protection Act 1975
Fisheries Act 1970, 1985
Territorial Sea and Fishing Zone Act 1970
Coastal Fisheries Protection Act 1979
Eastern Rocky Mountain Forest Conservation Act 1947
Forest Development and Research Act 1966, 1970
Migratory Birds Convention Act 1917, 1985
Game Export Act 1970
National Wildlife Week Act 1970
Canada Wildlife Act 1973

Environmental Expenditures

In fiscal year 1981-82, the federal government spent approximately $1.5 billion on environment-related programs in the form of direct provision of services, grants and contributions to industry and environmental groups and transfers to provincial governments. This figure amounted to approximately 2.2 per cent of total federal expenditures. By comparison, the estimated environment-related expenditures (in current dollars) for fiscal years 1972-73 and 1977-78 were about $360 000 and $785 000 respectively. Included in these totals are capital and operating expenditures for environmental protection, wildlife, forestry, land management, atmospheric services and research, parks, fisheries, water resources, sewage treatment, the International Joint Commission, Agriculture Canada's Pest and Disease Control Program, Health and Welfare's environmental health program, the Renewable Resources and Northern Environment Program of Indian Affairs and Northern Development, parts of the Atomic Energy Control Board budget, the Energy Conservation Program, and parts of the National Research Council budget. These figures do not include corporate tax deductions, tax credits, rebates on federal sales taxes, or reduced tariffs for the purchase and installation of environmental control or treatment equipment.

PROVINCIAL AND TERRITORIAL GOVERNMENTAL ACTIVITIES IN ENVIRONMENTAL MATTERS

Objectives, Organization and Legislation

As noted previously, much of the authority for environmental matters is vested in the provincial governments. In addition, territorial governments have more limited environmental responsibilities. It is therefore the duty of the provinces and, where appropriate, the territories, to establish and enforce pollution control standards; to implement and enforce policy on animal husbandry, hunting, forestry, mining and fishing activities; and to regulate land use. As a result each province or territory has a large number of statutes dealing with the regulation and conservation of the environment. Table 10.3 shows provincial and territorial environment-related legislation by jurisdiction. Table 10.4 lists statutes by subject area. (The first date indicates the year of promulgation of the statute or its incorporation into Revised Statutes, the second the year of most recent amendment.)

Environmental Expenditures

In fiscal year 1981-82, provincial and territorial governments spent about $2.2 billion, or 3.5 per cent of total provincial expenditures, on environmental programs. This sum includes programs for water and water resources, environmental protection, wildlife and fish, lands, forests, parks and historic sites, pest and disease control, environmental health, and environmental assessment. Accounting procedures vary from province to province; thus it is difficult to compare data. For example, some provinces include identifiable capital expenditures, others do not. In most cases, the federal contribution to shared-cost programs is not included, but this is not always the case. In some cases, the figures do not take into account cost recovery from other departments/appropriations. Revenue from fees and licences is usually not included. Furthermore, institutional structures vary from province to province and change with time; it is therefore not always possible to trace similar expenditure items from year to year.

It has also been estimated that local governments, which are subsidiary to provincial governments, spent about $2.5 billion in 1981 for environmental programs such as water purification and supply, sewage collection and treatment, and garbage and waste collection and disposal.

Summaries of governmental environment-related expenditures (in current dollars) for 1972-73, 1977-78 and 1981-82 are given in Table 10.5. For 1981-82, expenditures are also shown as a percentage of total government expenditures. The table includes data for each province and territory and the comparable figures for federal and local governments.

PRIVATE SECTOR ACTIVITIES IN ENVIRONMENTAL MATTERS

Industrial Activities

Spending for environmental protection by private industry in Canada includes both capital investment in plant and equipment and the annual operating costs of those facilities. The private sector is becoming increasingly aware of the sensitive nature of the environment, the limited character of some of its resources, and the need to pursue economic activities in a manner that will not only contribute to sustainable productivity in the future, but also minimize negative environmental impacts. Profit margins remain important, but corporate decision makers are also increasingly considering public environmental values and long-term perspectives.

Industry is also contributing technical and other expertise to the development of environmental standards and guidelines. Precise industry expenditures for all facets of environmental protection activities are difficult to obtain on a consistent basis, because accounting methods and the treatment of such expenditures vary. However, a small sectoral study commissioned for this report estimated that from 1981 to 1983, the Canadian forest industry spent some $696 million on pollution control activities. The

Text continues on page 239.

Table 10.2
International Environment-related Treaties/Conventions/Agreements of Potential Interest to Canada

Convention Title	Date and Place of Adoption	Date of Entry into Force	Approx. No. of Parties[1]	Canadian[2] Participation
A. General				
United Nations Convention on the Law of the Sea	Jamaica 10 December 1982	Not in force		Signed the Convention (1982)
B. Exploration and Management (Sea/Seabed/Outer Space)				
Convention on the Continental Shelf	Geneva 29 April 1958	10 June 1964	55	Yes (1970)
Convention on the High Seas	Geneva 29 April 1958	30 September 1962	57	No
Convention on Territorial Seas and Contiguous Zones	Geneva 29 April 1958	10 September 1964	46	No
Convention for the International Council for the Exploration of the Sea	Copenhagen 12 September 1964	22 July 1968	18	Yes (1968)
Treaty on Principles Governing the Activities of States in the Exploration and Use of Outer Space including the Moon and Other Celestial Bodies	London, etc. 27 January 1967	10 October 1967	71	Yes (1967)
Convention on International Liability for Damage Caused by Space Objects	London, etc. 20 March 1972	17 August 1972	—	Yes (1975)
Provisional Understanding Regarding Deep Seabed Matters	Geneva 3 August 1984	3 September 1984	8	No
C. Multilateral Conservation				
Convention on Nature Protection and Wildlife Preservation in the Western Hemisphere	Washington 12 October 1940	1 May 1942	7	No
International Plant Protection Convention	Rome 6 December 1951	3 April 1952	82	Yes (1953)
Convention on Wetlands of International Importance Especially as Waterfowl Habitat	Ramsar 2 February 1971	21 December 1975	34	Yes (1981)
Protocol to Amend Ramsar	Paris 12 March 1982	Not in force	9	Yes (1983)
Convention Concerning the Protection of the World Cultural & Natural Heritage	Paris 23 November 1972	17 December 1975	79	Yes (1976)
Convention on International Trade in Endangered Species of Wild Fauna and Flora	Washington 3 March 1973	1 July 1975	87	Yes (1975)
Agreement on Conservation of Polar Bears	Oslo 15 November 1973	26 May 1976	5	Yes (1976)
Convention on the Conservation of Migratory Species of Wild Animals	Bonn 23 June 1979	1 November 1983	15	No
D. Multilateral Fisheries				
International Convention for the Regulation of Whaling (Amended)	Washington 2 December 1946	10 November 1948	41	Yes (1949) Withdrew (1982)
International Convention for the Northwest Atlantic Fisheries	Washington 8 February 1949	3 July 1950 Terminated 31 December 1979	18	Yes (1950)
International Convention for the High Seas Fisheries of the North Pacific (Amended)	Tokyo 9 May 1952	12 June 1953	3	Yes (1953)
Convention on Fishing & Conservation of the Living Resources of the High Seas	Geneva 29 April 1958	20 March 1966	35	No
International Convention for the Conservation of Atlantic Tuna (Amended)	Rio de Janeiro 14 May 1966	21 March 1969	20	Yes (1969)
Convention on the Conduct of Fishing Operations in the North Atlantic	London 1 June 1967	26 April 1976	14	No
Interim Convention on Conservation of North Pacific Fur Seals (Amended)	Washington 9 February 1957	14 October 1957	4	Yes (1957)
Convention on Future Multilateral Cooperation in the Northwest Atlantic Fisheries	Ottawa 24 October 1978	1 January 1979	14	Yes (1979)
Convention for the Conservation of Salmon in the North Atlantic Ocean	Reykjavik 2 March 1982	1 October 1983	8	Yes (1983)
Eastern Pacific Ocean Tuna Fishing Agreement with Protocol	San José 15 March 1983	Not in force	3	No

Table 10.2, continued
International Environment-related Treaties/Conventions/Agreements of Potential Interest to Canada

Convention Title	Date and Place of Adoption	Date of Entry into Force	Approx. No. of Parties[1]	Canadian Participation
E. Pollution of the Seas				
Convention for the Prevention of Pollution of the Sea by Oil (OILPOL) (Amended)	London 12 May 1954	26 July 1958	70	Yes (1958)
International Convention on Civil Liability for Oil Pollution Damage (Amended)	Brussels 29 November 1969	19 June 1975	50	No (under review)
International Convention Relating to Intervention on the High Seas in Case of Oil Pollution Casualties	Brussels 29 November 1969	6 May 1975	45	No
International Convention on Establishment of an International Fund for Compensation for Oil Pollution Damage (Amended)	Brussels 18 December 1971	16 October 1978	28	No (under review)
Convention on the Prevention of Marine Pollution by Dumping of Wastes & Other Matter	London, etc. 29 December 1972	30 August 1975	58	Yes (1975)
Convention on Civil Liability for Oil Pollution Damage Resulting from Exploration and Exploitation of Seabed Mineral Resources	London 1 November 1977	Not in force	6	No
International Convention for the Prevention of Pollution from Ships (MARPOL)	London 2 November 1973	2 October 1983	15	No (under review)
F. Pollution of the Atmosphere				
Convention on Long-Range Transboundary Air Pollution	Geneva 13 November 1979	16 March 1983	30	Yes (1983)
Convention for the Protection of the Ozone Layer	Vienna 22 March 1985	Not in force	21	Yes (1985)
G. Nuclear Energy and Nuclear and Other Weapons				
Convention on Third Party Liability in the Field of Nuclear Energy	Paris 29 July 1960	1 April 1968	14	No
The Vienna Convention on Civil Liability for Nuclear Damage	Vienna 21 May 1963	12 November 1977	10	No
Treaty Banning Nuclear Weapon Tests in the Atmosphere, in Outer Space and Under Water	Moscow 5 August 1963	10 October 1963	112	Yes (1964)
Treaty on Non-Proliferation of Nuclear Weapons	London, etc. 1 July 1968	5 March 1970	119	Yes (1970)
Treaty on Prohibition of Emplacement of Nuclear Weapons or Other Weapons of Mass Destruction on the Sea-Bed, Ocean Floor and in the Subsoil	London, etc. 11 February 1971	18 May 1972	73	Yes (1972)
Convention Relating to Civil Liability in the Field of Maritime Carriage of Nuclear Material	Brussels 17 December 1971	15 July 1975	11	No
Convention on Prohibition of the Development, Production & Stockpiling of Bacteriological and Toxic Weapons	London, etc. 10 April 1972	26 March 1975	99	Yes (1975)
Convention on Prohibition of Military or any other Hostile Use of Environmental Modification Techniques	Geneva 18 May 1977	5 October 1978	47	Yes (1981)
Convention on the Physical Protection of Nuclear Material	Vienna 26 October 1979	Not in force	9	No (under review)

[1]Information concerning the number of parties is highly time-dependent, and the figures shown here are based on information available as of May 1985.
[2]Full participation in a Convention means that Canada has ratified the convention. The table indicates a number of cases where Canada has signed a convention, but the government has not yet ratified it.

Source: Information from several sources, inluding "Register of International Treaties and Other Agreements in the Field of the Environment", UNEP/GC/Inf./11, May 1984; "Status of Multilateral Conventions Related to the Environment", a series of charts compiled by IUCN's Environmental Law Centre, 1981; and personal communications from the Department of External Affairs, the Department of Transport, the Department of Fisheries and Oceans, and the Atomic Energy Control Board.

Table 10.3
Provincial/Territorial Environment-related Legislation[1]

British Columbia

Department of Environment Act 1980[2]
Environment Management Act 1981, 1983
Health Act 1971, 1983
Weather Modification Activity Act 1973, 1983
Motor Vehicle Act 1979
Water Act 1960, 1979
River Bank Protection Act 1979
Park Act 1965
Land Act 1970, 1979
Environment & Land Use Act 1971, 1979
Ecological Reserves Act 1971, 1983
Utilities Commission Act 1980
Pesticide Control Act 1977, 1980
Pipeline Act 1979
Litter Act 1970, 1979
Waste Management Act 1982, 1983
Mining Regulations Act 1979
Agriculture Land Commission Act 1972, 1977
Range Act 1978
Soil Conservation Act 1977, 1979
Agriculture and Rural Development Act 1982
Fisheries Act 1979, 1982
Forest Act 1979
Dogwood etc. Protection Act 1960
Creston Valley Wildlife Act 1968, 1977
Wildlife Act 1973
Bee Act 1980

Alberta

Environment Council Act 1970, 1980
Department of Environment Act 1971, 1981
Public Health Act 1970, 1980
Environmental Research Trust Act 1980, 1981
Clean Air Act 1971, 1983
Water Resources Act 1970, 1978
Clean Water Act 1980, 1983
Ground Water Development Act 1980
Coal Conservation Act 1973, 1982
Hydro & Electric Energy Act 1980, 1982
Oil and Gas Conservation Act 1970, 1983
Public Lands Act 1970, 1980
Wilderness Areas Act 1971, 1981
Provincial Parks Act 1974
Land Surface Conservation and Reclamation Act 1973, 1983
Agricultural Chemicals Act 1970, 1984
Radiation Protection Act 1970, 1980
Hazardous Chemicals Act 1978, 1982
Pipeline Act 1975, 1983
Transport of Dangerous Goods Act 1982
Special Waste Management Corporation Act 1982
Litter Act 1972, 1980
Beverage Containers Act 1977, 1982
Quarries Regulation Act 1980
Soil Conservation Act 1970, 1980
Irrigation Act 1970, 1980
Forest Reserves Act 1970, 1980
Forests Act 1971, 1980
Forest & Prairie Protection Act 1971, 1980
Wildlife Act 1970
Recreation Parks, and Wildlife Foundation Act 1977
Bee Act 1972

Saskatchewan

Department of Environment Act 1972, 1984
Environmental Management & Protection Act 1984
Department of Parks and Renewable Resource Act 1983
Public Health Act 1978, 1983
Air Pollution Control Act 1978, 1983
Ground Water Conservation Act 1959, 1978
Water Power Act 1965, 1978
Water Pollution Control Assistance Act 1969
Pollution (Livestock) Control Act 1971, 1984
Sewage Drainage Inquiry Act 1978, 1983
Municipal Public Works Act 1978, 1983
Water Corporation Act 1984
Drainage Appeal Board Act 1984
Provincial Parks & Protected Areas Act 1965, 1978
Conservation & Development Act 1965, 1978
Environmental Assessment Act 1980
Ecological Reserves Act 1980
Radiation Health & Safety Act 1978
Pest Control Products Act 1978, 1984
Oil & Gas Conservation, Stabilization & Development Act 1978
Litter Control Act 1978
Mineral Resources Act 1978
Scrap Vehicles Act 1978
Agriculture Development Adjustment Act 1965, 1978
Fisheries Act 1965, 1978
Forest Act 1965, 1978
Prairie & Forest Fires Act 1965, 1978
Apiaries Act 1978, 1979
Wildlife Act 1979, 1982
Critical Wildlife Habitat Protection Act 1984

Manitoba

Clean Environment Act 1972, 1982
Public Health Act 1970, 1980
Mining & Metallurgy Compensation Act 1970
Water Resources Administration Act 1970
Rivers & Streams Act 1970, 1972
Ground Water & Water Wells Act 1970, 1972
Crown Lands Act 1970
Provincial Park Lands Act 1972
Ecological Reserves Act 1981
Pesticides & Fertilizers Control Act 1976, 1983
Mines Act 1973
Plant Pests & Diseases Act 1963
Dutch Elm Disease Act 1980
Fisheries Act 1969
Fishermen's Assistance & Pollution Liability Act 1970
Forest Act 1964, 1974
Wildlife Act 1980
Industrial Minerals Drilling Act 1977

Ontario

Environmental Protection Act 1971, 1983
Public Health Act 1980
Health Protection and Promotion Act 1983
Beds of Navigable Waters Act 1911
Ontario Water Resources Act 1956, 1983
Ontario Drainage Act 1963, 1980
Lakes & Rivers Improvement Act 1970, 1980
Beach Protection Act 1970, 1980
Public Lands Act 1970, 1972
Conservation Authorities Act 1970, 1980
Provincial Parks Act 1970
Wilderness Areas Act 1970, 1980
Tourism Act 1970, 1980
Environmental Assessment Act 1976, 1980
Public Utilities Act 1982
Petroleum Resources Act 1971
Pesticides Act 1974, 1981
Dangerous Goods Transportation Act 1981
Motorized Snow Vehicles Act 1968, 1982
Highway Traffic Act 1980
Waste Management Corporation Act 1981
Mining Act 1980
Pits & Quarries Control Act 1980
Till Drainage Act 1909, 1983
Weed Control Act 1927, 1983
Wild Rice Harvesting Act 1960, 1971
Agriculture Rehabilitation & Development Act 1970
Plant Diseases Act 1970, 1980
Top Soil Preservation Act 1977, 1980
Abandoned Orchards Act 1978
Game & Fish Act 1970
Tree Planting Act 1927, 1979
Forestry Act 1970
Algonquin Forest Authority Act 1974, 1980
Forest Fires Prevention Act 1970
Forest Tree Pest Control Act 1970
Crown Timber Act 1970
Woodlands Improvement Act 1970
Bee Act 1970
Endangered Species Act 1971, 1980

Quebec

Environment Quality Act 1972, 1984
Public Health Protection Act 1972, 1979
Ministère de l'environnement 1979, 1982
Artificial Inducement of Rain Act 1970, 1979
Water Courses Act 1964, 1978
Provincial Parks Act 1964
Lands & Forests Act 1964, 1974
Tourism, Fish and Game Department Act 1964
James Bay Development Act 1971
Ecological Reserves Act 1977, 1984
Transport Act 1972, 1981
Protection of Agricultural Land Act 1978
Plant Protection Act 1964, 1973
Tree Protection Act 1964
Forest Resources Utilization Act 1964
Conservation and Development of Wildlife Act 1983

Table 10.3, continued
Provincial/Territorial Environment-related Legislation[1]

New Brunswick

Clean Environment Act 1973, 1983[2]
Health Act 1973, 1983
Motor Vehicle Act 1971, 1983
Tourism Development Act 1971
Ecological Reserves Act 1973, 1979
Mining Act 1973, 1983
Pipeline Act 1976, 1983
Parks Act 1977, 1982
Marshland Reclamation Act 1977, 1979
Pesticides Control Act 1973, 1982
Oil & Natural Gas Act 1976, 1983
Highway Act 1973, 1983
Quarriable Substances Act 1973, 1983
Unsightly Premises Act 1975, 1981
Beverage Containers Act 1977, 1980
Agricultural Rehabilitation & Development Act 1973
Plant Diseases Act 1978
Potato Disease Eradication Act 1979
Fish & Wildlife Act 1980, 1984
Forest Fires Act 1973, 1983
Crown Lands & Forests 1976, 1983
Endangered Species 1973, 1974
Apiary Inspection Act 1973, 1974

Nova Scotia

Environmental Protection Act 1973, 1975
Public Health Act 1967, 1973
Motor Vehicles Act 1967, 1982
Water Act 1967, 1972
Well Drilling Act 1967
Beaches Preservation & Protection Act 1975
Provincial Parks Act 1967
Lands & Forests Act 1926, 1967
Marshland Reclamation Act 1967
Culture, Fitness and Recreation Act 1973
Special Places Protection Act 1980
Emergency Measures Act 1967
Pest Control Products Act 1970
Dangerous Goods Transportation Act 1982
Oil and Gas Production and Conservation Act 1984
Salvage Yards Licensing Act 1969, 1970
Smelting and Refining Encouragement Act 1967
Beverage Containers Act 1975
Mineral Resources Act 1975
Agriculture & Marketing Act 1967
Weed Control Act 1967
Fisheries Act 1977
Aquaculture Act 1983
Forest Improvement Act 1967
Nova Scotia Museums Act 1967

Prince Edward Island

Environmental Protection Act 1975, 1983
Public Health Act 1980
Highway Traffic Act 1974, 1981
Water & Sewerage Act 1974, 1983
Well Drillers Act 1974
Recreation Development Act 1969, 1974
Planning Act 1974, 1983
Municipalities Act 1983
Dangerous Goods Transport Act 1981
Pesticides Control Act 1984
Mineral Resources Act 1974, 1978
Automobile Junkyard Act 1974, 1976
Unsightly Property Act 1975, 1977
Agricultural Rehabilitation & Development Act 1962
Fish Inspection Act 1956
Fish & Game Protection Act 1974, 1979
Forestry Act 1956

Newfoundland

Department of Environment Act 1981, 1983
Health Act 1970, 1979
Waters Protection Act 1970, 1981
Well Drilling Act 1981
Provincial Parks Act 1953
Crown Lands Act 1970, 1983
Development Areas (Lands) Act 1970, 1982
Environmental Assessment Act 1980, 1983
Wilderness & Ecological Reserves Act 1980, 1983
Pesticides Control Act 1970, 1983
Petroleum and Natural Gas Act 1970, 1981
Nuisances and Municipal Regulations Act 1970, 1979
Waste Material Disposal Act 1973, 1981
Ore Treatment Tailings (Labrador) Act 1973
Quarry Materials Act 1975
Rural Agriculture Development Act 1973
Fisheries Act 1970, 1980
Fisheries Development Authority Act 1982
Forest Fires Act 1970, 1973
Forest Travel Act 1970
Newfoundland and Labrador Forest Protection Act 1970
Forest (exchange & acquisition) Act 1970
Forest Land Management & Taxation Act 1974
Forests & Lands Act 1981
Wildlife Act 1970, 1982

Yukon

Public Health Ordinance 1971
Area Development Ordinance 1971, 1975
Historical Sites and Monuments Ordinance 1971, 1975
Lands Ordinance 1972, 1981
Parks 1979, 1980
Land Planning Ordinance 1982
Noise Prevention Ordinance 1971
Agricultural Development Ordinance 1982
Forest Protection Ordinance 1971, 1980
Animal Protection Ordinance 1977
Wildlife Act 1980, 1982

Northwest Territories

Public Health Ordinance 1957, 1977
Area Development Ordinance 1956, 1979
Environmental Protection Ordinance 1973
Scientists Ordinance 1974
Water Resources Agreement Ordinance 1983
Commissioner's Land Ordinance 1969
Historic Resource Ordinance 1970
Territorial Parks Ordinance 1973, 1983
Travel & Tourism Ordinance 1983
Pesticides Ordinance 1970
Petroleum Products Ordinance 1974, 1975
Mining Safety Ordinance 1974
Transport of Dangerous Goods Ordinance 1982
Herd and Fencing Ordinance 1974, 1975
Freshwater Fish Marketing Ordinance 1969
Forest Protection Ordinance 1959, 1977
Wildlife Ordinance 1978

[1]See Table 10.4 for listing by subject.
[2]First date is date of promulgation or incorporation into Revised Statutes; second is date of latest amendment.

Table 10.4
Provincial/Territorial Environment-related Legislation, by Subject[1]

Agriculture	
Agric. Land Com. '72 '77[2]	BC
Soil Conservation '77 '79	BC
Range '78	BC
Agric. & Rural Devel. '82	BC
Soil Conservation '70 '80	ALTA
Irrigation '70 '80	ALTA
Agric. Devel. & Adjust. '65 '78	SASK
Plant Pests & Diseases '63	MAN
Dutch Elm Disease '80	MAN
Agric. Rehab. & Dev. '70	ONT
Plant Diseases '70 '80	ONT
Abandoned Orchards '78	ONT
Till Drainage '09 '83	ONT
Weed Control '27 '73	ONT
Wild Rice Harvesting '60 '71	ONT
Top Soil Preservation '77 '80	ONT
Prot. of Agric. Land '78	QUE
Plant Protection '64 '73	QUE
Agric. Rehab. & Devel. '73	NB
Plant Diseases '78	NB
Potato Disease Erad. '79	NB
Agric. & Marketing '67	NS
Weed Control Act '67	NS
Agric. Rehab. & Devel. '62	PEI
Rural Agric. Devel. '73	NFLD
Herd & Fencing Ord. '74 '75	NWT
Animal Protection '77	Y
Agricultural Devel. Ord. '82	Y

Fisheries	
Fisheries '79 '82	BC
Fisheries '65 '78	SASK
Fisheries '69	MAN
Fish. Assist. & Poll. Liab. '70	MAN
Game & Fish '70	ONT
Tourism, Fish & Game '64	QUE
Fish & Wildlife '81	NB
Fisheries '77	NS
Aquaculture '83	NS
Aquaculture '83	NS
Fish Inspection '56	PEI
Fish & Game Prot. '74 '79	PEI
Fisheries '70 '80	NFLD
Fisheries Dev. Auth. '82	NFLD
Freshwater Fish Mark. Ord. '69	NWT

Forestry	
Forest '79	BC
Forest Reserves '70 '80	ALTA
Forests '71 '80	ALTA
Forest & Prairie Prot. '71 '80	ALTA
Forest '65 '73	SASK
Prairie & Forest Fires '65 '78	SASK
Forest '64 '74	MAN
Tree Planting '27 '79	ONT
Forestry '70	ONT
Forest Fires Preven. '70	ONT
Forest Tree Pest Control '70	ONT
Crown Timber '70	ONT
Woodlands Improv. '70	ONT
Algonquin Forest Auth. '74 '80	ONT
Lands & Forests '64 '74	QUE
Tree Protection '64	QUE
Forest Res. Utiln. '64	QUE
Forest Fires '73 '83	NB
Crown Lands & Forests '76 '83	NB
Lands & Forests '26 '67	NS
Forest Improv. '67	NS
Forestry '56	PEI
Forest Fires '70 '73	NFLD
Forest Travel '70	NFLD
Nfld. & Lab. Forest (Prot.) '70	NFLD
Forest (exch. & acquis.) '70	NFLD
Forest Land Mgmt. & Tax '74	NFLD
Forests & Lands '81	NFLD
Forest Protection Ord. '59 '77	NWT
Forest Protection '71 '80	Y

Wildlife	
Dogwood etc. Prot. '60	BC
Creston Valley Wildlife '68 '77	BC
Widlife '73	BC
Bee '80	BC
Wildlife '70	ALTA
Bee '72	ALTA
Recreation, Parks, Wildlife '77	ALTA
Wildlife '79	SASK
Critical Wildlife Hab. Prot. '84	SASK
Apiaries '78 '79	SASK
Wildlife '80 '82	MAN
Game & Fish '70	ONT
Bee '70	ONT
Tourism '70 '80	ONT
Endangered Species '71 '80	ONT
Tourism, Fish & Game '64	QUE
Conserv. & Devel. Wildlife '83	QUE
Apiary Inspection '73 '74	NB
Fish and Wildlife '80 '84	NB
Endangered Species '75 '82	NB
Nova Scotia Museum Act '67	NS
Fish & Game Prot. '74 '79	PEI
Wildlife '70 '82	NFLD
Wildlife Ordinance '78	NWT
Animal Prot. Ord. '77	Y
Wildlife '81 '82	Y

General	
Dept. of Env't. '80	BC
Health '71 '83	BC
Env't. Mgmt. '81 '83	BC
Public Health '70 '80	ALTA
Env't. Council '70 '80	ALTA
Dept. of Env't. '71 '81	ALTA
Env'l. Research Trust '80 '81	ALTA
Dept. of Env't. '72 '84	SASK
Dept. Parks & Ren. Res. '83	SASK
Public Health '78 '83	SASK
Env'l. Mgmt. & Protection '84	SASK
Public Health '70- '80	MAN
Clean Environment '72 '82	MAN
Env'l. Protection '71 '83	ONT
Public Health '80	ONT
Health Protection & Promotion '83	ONT
Env't. Quality '72 '84	QUE
Pub. Health Prot. '72 '79	QUE
Min. of the Environment '79 '82	QUE
Clean Environment '73 '83	NB
Dept. of Health '70 '79	NB
Public Health '67 '73	NS
Env'l. Protection '73 '75	NS
Public Health '80	PEI
Env'l. Protection '75 '83	PEI
Health '70 '79	NFLD
Dept. of Env't. '81 '83	NFLD
Pub. Health Ord. '57 '77	NWT
Area Develop. Ord. '56 '79	NWT
Env'l. Prot. Ord. '73	NWT
Scientists Ord. '74	NWT
Public Health Ord. '71	Y
Area Develop. Ord. '71 '75	Y

Table 10.4, continued

Provincial/Territorial Environment-related Legislation, by Subject[1]

Air/Atmosphere	
Weather Modification '73 '83[2]	BC
Motor Vehicle '79	BC
Clean Air '71 '83	ALTA
Air Polln. Control '78 '83	SASK
Mining & Metallurgy '70	MAN
Artificial Induce. Rain '70 '79	QUE
Motor Vehicle '71 '83	NB
Motor Vehicles '67 '82	NS
Highway Traffic '74 '81	PEI

Water	
Water '60 '79	BC
River Bank Prot. '79	BC
Water Resources '70 '78	ALTA
Oil & Gas Conserv. '70 '83	ALTA
Clean Water '80'83	ALTA
Coal Conservation '73 '82	ALTA
Ground Water Devel. '80	ALTA
Hydro & Electric Energy '80 '82	ALTA
Water Power '65 '78	SASK
Ground Water Conserv. '59 '78	SASK
Water Polln. Con'l Assist. '69	SASK
Polln. by Livestock Cont. '71 '84	SASK
Sewage Drainage Inquiry '78 '83	SASK
Municip. Public Works '78 '83	SASK
Water Corporation '84	SASK
Drainage Appeal Board '84	SASK
Water Res. Admin. '70	MAN
Rivers & Streams '70 '72	MAN
Ground Wtr. & Wtr. Wells '70 '72	MAN
Beds of Navig. Waters '11	ONT
Ont. Water Resources '56 '83	ONT
Drainage '63 '80	ONT
Lakes & Rivers Improv. '70 '80	ONT
Beach Prot. '70 '80	ONT
Water Courses '64 '78	QUE
Water '67 '73	NS
Well Drilling '67	NS
Beaches Preserv. & Prot. '75	NS
Water & Sewerage '74 '83	PEI
Well Dr'llers '74	PEI
Waters Protection '70 '81	NFLD
Well Drilling '81	NFLD
Water Resources Agr. Ord. '83	NWT

Land-Use Planning	
Park '65	BC
Land '70 '79	BC
Env't. & Land Use '71 '79	BC
Ecol. Reserves '71 '83	BC
Utilities Commission '80	BC
Public Lands '70 '80	ALTA
Wilderness Areas, etc. '71 '81	ALTA
Prov. Parks '74	ALTA
Land Surf. Conserv. '73 '83	ALTA
Prov. Parks, Prot. Areas '65 '78	SASK
Conservation & Devel. '65 '78	SASK
Env'l. Assess. '80 '83	SASK
Ecol. Reserves '80	SASK
Crown Lands '70	MAN
Prov'l. Park Lands '72	MAN
Ecological Reserves '81	MAN
Public Lands '70 '72	ONT
Conserv. Auth. '70 '80	ONT
Prov. Parks '70	ONT
Wilderness Areas '70 '80	ONT
Env'l. Assess. '74 '81	ONT
Public Utilities '82	ONT
Prov. Parks '64	QUE
Lands & Forests '64 '74	QUE
James Bay Develop. '71	QUE
Ecol. Reserves '77 '84	QUE
Tourism Devel. '71	NB
Ecol. Reserves '73 '79	NB
Parks '77 '82	NB
Marshland Reclam. '77 '79	NB
Prov. Parks '67	NS
Lands & Forests '26 '67	NS
Marshland Reclam. '67	NS
Special Places Protection '80	NS
Recreation Development '69 '74	NS
Planning '74 '83	PEI
Municipalities '83	PEI
Prov'l. Parks '53	NFLD
Crown Lands '70 '83	NFLD
Devel. Areas (Lands) '70 '82	NFLD
Env'l. Assess. '80 '83	NFLD
Wilderness & Ecol. Res. '80 '83	NFLD
Commissioners Land Ord. '69	NWT
Historic Resources Ord. '70	NWT
Territorial Parks Ord. '73 '83	NWT
Travel & Tourism Ord. '83	NWT
Hist. Sites & Mon. Ord. '71 '75	Y
Lands Ord. '72 '81	Y
Parks '79 '80	Y
Land Planning Ord. '82	Y

Hazardous Chemicals/Products	
Pesticide Control '77 '80	BC
Pipeline '79 '81	BC
Agric. Chemicals '70 '84	ALTA
Radiation Protection '70 '80	ALTA
Hazardous Chemicals '78 '82	ALTA
Pipeline '75 '83	ALTA
Transp. Danger. Goods '82	ALTA
Spec. Waste Mgmt. Corp. '82	ALTA
Radiation Health & Safety '78	SASK
Pest Control Prod. (Sask.) '78 '84	SASK
Oil & Gas Conserv., Dev. '78	SASK
Pest. & Fert. Control '76 '83	MAN
Pesticides '71 '82	ONT
Highway Traffic '80	ONT
Dangerous Goods Transp. '81	ONT
Petroleum Resources '71	ONT
Transport '72 '81	QUE
Pesticide Control '73 '82	NB
Oil & Natural Gas '76 '83	NB
Pipeline '76 '83	NB
Pest Control Prod. '70	NS
Dangerous Goods Transp. '82	NS
Dangerous Goods Transp. '81	PEI
Pesticides Control '84	PEI
Pesticides Control '70 '83	NFLD
Petroleum & Nat. Gas '70 '81	NFLD
Pesticides Ord. '70	NWT
Petroleum Prod. Ord. '74 '75	NWT
Mining Safety Ord. '74	NWT
Transport Dangerous Goods '82	NWT

Solid Waste/Noise	
Litter '70 '79	BC
Mining Regulations '79	BC
Waste Mgmt. '82 '83	BC
Litter '72 '80	ALTA
Beverage Containers '77 '82	ALTA
Quarries Regulation '80	ALTA
Litter Control '78	SASK
Mineral Resources '78	SASK
Scrap Vehicles '78	SASK
Mines '73	MAN
Indust. Minerals Drill. '77	MAN
Mining '80	ONT
Pits & Quarries Control '80	ONT
Ont. Waste Mgmt. Corp. '81	ONT
Motorized Snow Veh. '68 '82	ONT
Highway '73 '83	NB
Quarriable Substances '73 '83	NB
Unsightly Premises '75 '81	NB
Mining '73 '83	NB
Beverage Containers '77 '80	NB
Beverage Containers '75	NS
Mineral Resources '75	NS
Mineral Resources '74 '78	PEI
Automobile Junkyard '74 '76	PEI
Unsightly Property '73 '77	PEI
Waste Material Disp. '73 '81	NFLD
Nuisance & Municip. Reg. '70 '79	NFLD
Ore Treat. Tailings (Lab.) '73	NFLD
Quarry Materials '75	NFLD
Noise Preven. Ord. '71	Y

[1]See Table 10.3 for listing by province.

[2]First date shown is year of promulgation or incorporation into Revised Statutes; second date is year of latest amendment.

Table 10.5
Provincial/Territorial and Local Government Environmental Expenditures[1]
(current dollars)

	Environmental Expenditures[2] and Percentage Change					
	Thousands of dollars		Percentage change	Thousands of dollars	Percentage change	Environmental as percentage of Total Expenditures
Jurisdiction	1972-73	1977-78	1972-73/1977-78	1981-82	1977-78/1981-82	1981-82
British Columbia	70 672	188 389	166.6	384 500	104.1	5.6
Alberta	36 250	119 147	228.7	562 684	372.3	8.1
Saskatchewan	5 914	13 192	123.1	29 091	120.5	1.2
Manitoba	25 187	53 228	111.3	69 374	30.3	2.9
Ontario	218 020	424 629	94.8	619 802	46.0	3.2
Quebec	83 873	253 320	202.0	404 485	59.7	2.0
New Brunswick	12 096	35 291	191.8	52 225	48.0	2.9
Nova Scotia	8 219	23 399	184.7	46 200	97.4	2.2
Prince Edward Island	2 682	7 937	195.9	10 458	31.8	3.0
Newfoundland	11 794	29 079	146.6	51 488	77.1	3.8
Northwest Territories	1 243	16 665	1 241.0	20 725	24.4	5.3
Yukon	280	3 245	1 059.0	3 568	10.0	2.6
Local Governments[3]	762 717	1 848 283	142.3	2 533 807	37.1	
Federal Government	361 988	783 431	116.4	1 510 472	92.8	2.2

[1]Because institutional structures differ from one jurisdiction to another, direct comparisons are unrealistic.
[2]See text for brief outline of major activities included in each jurisdiction's data.
[3]Local government expenditures are for calendar years 1972, 1977 and 1981 (estimated).

Table 10.6
Estimated Environmental Expenditures by Industrial Sector

	Expenditures[1]	(000s current dollars)	
Sector	1975-77	1978-1980	1981-83
Forest Industry	299 999	308 590	696 477
Mining Industry	77 000	86 000	96 000
Petroleum Industry	78 917	207 405	299 114

[1]These figures should be considered an indication of order of magnitude; they are probably on the low side because environmental expenditures were reported in a variety of ways by individual firms; for example, some companies included operating costs as an expenditure while others did not.

Source: Thurlow and Associates, 1984. Special survey conducted for this report.

petroleum industry spent some $299 million, while the mining industry sector spent another $96 million. These data for the three sectors, along with estimates for 1975-77 and 1978-80, are shown in Table 10.6.

Environmental Activities of Voluntary Organizations

As in other developed countries, the environmental voluntary sector in Canada is active and vociferous in lobbying governments and influencing the general public on environmental protection and conservation matters. Some Canadians provide voluntary services or funding that assist governments in pursuing their environmental policies. Others, through their actions and expressed concern for the environment, give more direct aid. These services include severe weather watches, bird breeding surveys, bird banding, the interpretation and guide services of co-operating associations and volunteers in the national parks system, and the wildlife funding and management activities of such groups as Ducks Unlimited, the Wildlife Habitat Canada Foundation, the Société linnéenne du Québec Inc., and the Friends of Wye Marsh. Governments at all levels would be hard-pressed to provide these services.

Environmental non-government organizations (ENGOs) are public interest organizations set up to foster the pursuit of specific environmental goals by individuals and by governments. They are usually funded by contributions from members, business and government. Their environmental interests range from single issues (e.g., the Canadian Coalition on Acid Rain) to a multiplicity of concerns (e.g., the Canadian Nature Federation). ENGOs as a whole boast extensive memberships, and the estimated annual expenditures of some 30 such Canadian organizations total more than $40 million. ENGOs provide alternative sources of information, help to identify problems, give alternative analyses of issues, represent society's diverse interests, and act as environmental watchdogs on government and industrial activities.

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INTRODUCTION

Canada's environment is influenced by forces beyond its boundaries as well as by actions within. Export markets for its natural resources (agricultural products, fish, forest products and minerals) contribute significantly to Canada's high standard of living. It is important to appreciate the stresses caused by the exploitation of these natural resources. In particular, it is important to be aware of the global supply of and demand for such resources and their possible implications for Canada in the future. Canada is indeed part of the global village and cannot live in isolation from needs and actions in other parts of the world.

POPULATION GROWTH

The more people there are on earth, the greater the need for careful husbandry of limited resources. Many studies have been made of population growth rates for different countries and of the social factors underlying some of the differences. Rural to urban migrations have also been studied extensively. Here, it is sufficient to recognize four factors:

1. The world's population continues to grow rapidly; it is expected to rise from about 4.677 billion in 1983 to more than 6.1 billion by the year 2000.
2. The time needed for the world's population to double has been shortening, although the growth curve shows some signs of slackening.
3. These events are dictated largely by changes taking place in developing countries, where the primary concern of millions of people is sheer survival.
4. The impact of population on the environment is, however, more than a matter of simple population growth. Account must be taken of the disproportionately higher rate of per capita consumption of materials and energy in the developed world. One dramatic statistic, cited in the World Conservation Strategy, estimates that one Swiss consumes as much as 40 Somalis consume.

GLOBAL NATURAL RESOURCES

Agricultural Resources

Data for grain production and arable area, with projections to the year 2000, give a broad indication of trends in the supply of and demand for agricultural output.[12] Forecasting such trends is difficult, and the projections must be seen as broad directional indicators only. The projections are based on the Global 2000 Alternative I scenario, which assumes median world population and per capita income growth rates, weather conditions comparable to the past 25 years, and petroleum prices comparable to those of 1974-76.

Under these conditions, past and future changes in world grain production and world arable land are shown in Figure 11.1. Data are expressed as both world totals and totals per capita to show the effect of increasing populations.

While grain production is projected to increase steadily as a result of crop selection, cropping practice, fertilizers, and pesticides, the increase in production per capita is projected to taper off. The projection shows that the increase in arable land has already begun to slow down. The amount of arable land per capita has been declining steadily and, by 2000, may be only about one-half the 1950 figure. If these projections are borne out, there will be enormous pressure to increase productivity (yield per hectare), and those countries exporting grain will be expected to provide more.

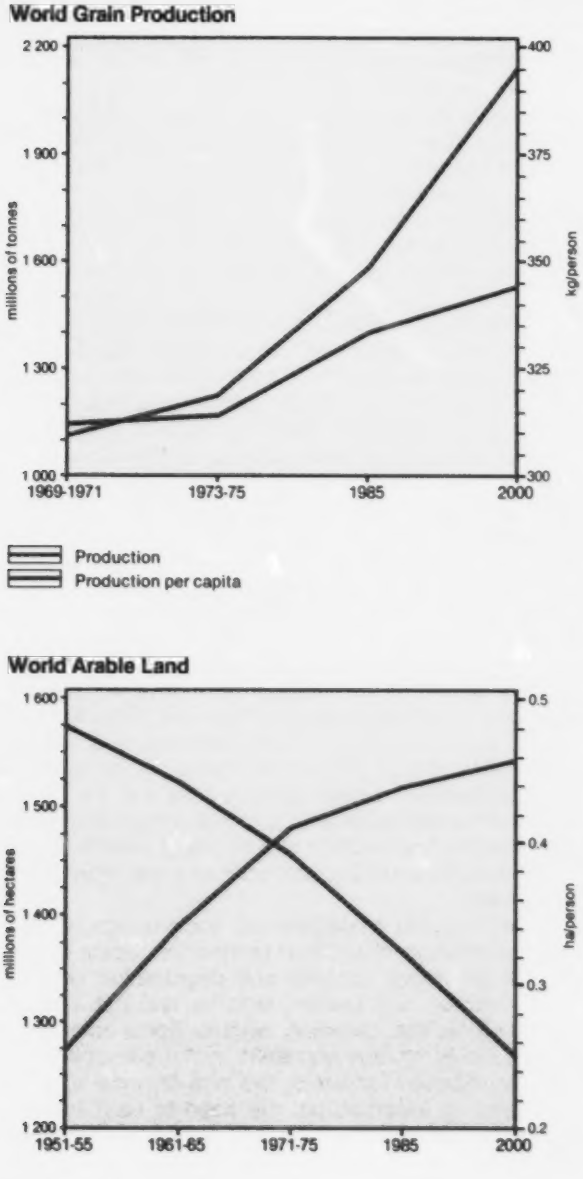
One factor contributing significantly to increased productivity is the use of fertilizers. The Global 2000 Report indicates that the average world consumption of fertilizers rose from 15 kilograms per hectare (kg/ha) of arable land between 1951 and 1955 to 30 kg/ha in 1961-65, and to 55 kg/ha in 1971-75. Fertilizer consumption was expected to reach 90 kg/ha by 1985 and 145 kg/ha by the year 2000. Corresponding figures for industrialized countries are 40, 65, 100, 145 and 210 kg/ha, and for less developed countries (LDCs) 2, 5, 20, 40, 80 kg/ha. The application of commercial fertilizers in the LDCs, although lower than in the industrialized countries, is growing at a more rapid rate. The projections for 1985 and 2000 are necessarily speculative; nevertheless, the increasing use of commercial fertilizers adds to the cost of production and to dependence on the development of a chemical fertilizer industry. Whether the recent increase in food production experienced in Asia can be maintained at a sustainable level is still uncertain. Any gaps between food production and needs at a world scale will result in increasing pressure to grow more food in Canada.

Both natural processes and socio-economic factors will strongly affect food production. Some of the natural processes include soil degradation due to water logging, salinization, erosion, and the loss of disease-resistant breeding strains. Socio-economic factors could include shortfalls in the production of petroleum-based fertilizers, the loss of good agricultural land to urbanization, the need to earn foreign exchange (plantation crops), and the use of cropland for alcohol-based fuels. The combined effects of natural processes, population growth and economic forces on agricultural production are difficult to predict, but there are many signals to suggest that there will be growing incidences of food crises throughout different parts of the world.

Fisheries and Aquatic Resources

The annual global catch of all living fresh- or saltwater organisms was estimated to be about 75 million tonnes in 1980.[11] Figure 11.2 shows aquatic produc-

Figure 11.1
World Grain Production and Arable Land



Source: U.S. Council on Environmental Quality and Department of State, *The Global 2000 Report to the President*, Volume Two, 1980.

tion from the early 1960s to the year 2000 by developing countries, developed countries and the world.

Projections of the future need for aquatic organisms are at best educated guesses. Demand has been projected to climb from about 90 million tonnes to 115 million tonnes in 1990 and 135 million tonnes in 2000. For developing countries, the proportion of the world's need will increase from about 40 per cent in 1980 to just under 60 per cent in 2000. Given that the annual increase in the global catch has decreased substantially, the 1980 shortfall between catch and need (15 million tonnes) will probably grow to about 40 million tonnes (or 30 per cent of need) by 2000. This shortfall is likely to be distributed unevenly.

More precise estimates of the shortfall are impossible without improved information about the sustainable productive capacities of the world's fisheries and the potential contributions of aquaculture. Factors such as ocean pollution, caused by increases in world shipping, and the alteration of estuarine ecosystems (on which much commercial fishing is dependent), as a result of economic development, may cause a reduction in productive capacity. This will mean greater pressure to develop aquaculture and to exploit unconventional fish species such as krill.

Canada's share of the world catch of fish, crustaceans, molluscs and other aquatic organisms increased between 1975 and 1981. Overall, the world catch increased from 66.1 to 74.8 million tonnes (a 13-per cent increase). Canada's share increased from 0.99 to 1.36 million tonnes (a 37-per cent increase).[7] While this increase is small compared with estimated shortfalls, it probably reflects a renewed Canadian interest in the proper management of the world's fisheries following the 1977 establishment of the 200-mile fishing zone.

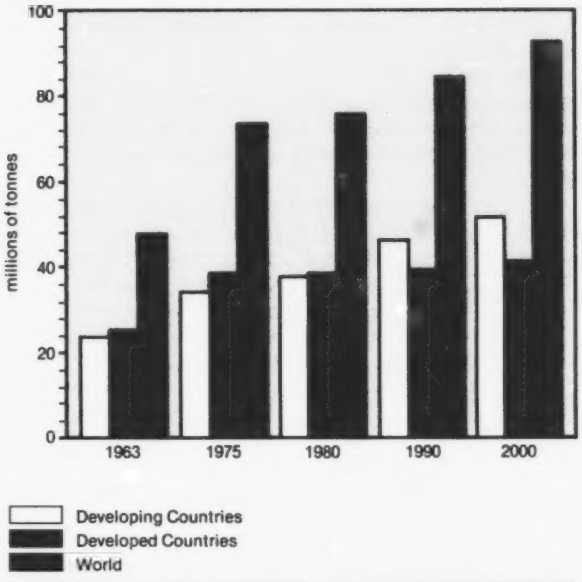
Forest Resources

Reliable worldwide information on forests is very limited. Rough estimates indicate that in the mid-1950s, forests covered over one-fourth of the world's land area. By 1980 the estimate was one-fifth, and by the year 2000 it may decline to one-sixth. Estimates of closed forest resources in 1978 and 2000 for the world and for developed and developing countries are shown in Figure 11.3.

Many countries lack detailed information on such important factors as changes in the amount, composition and location of growing stock, harvesting rate (real or sustainable), and the expected levels of need and effective demand. The absence of such information makes serious long-term planning almost impossible. Many of these problems may be substantially reduced in the future as remote-sensing techniques come into use.

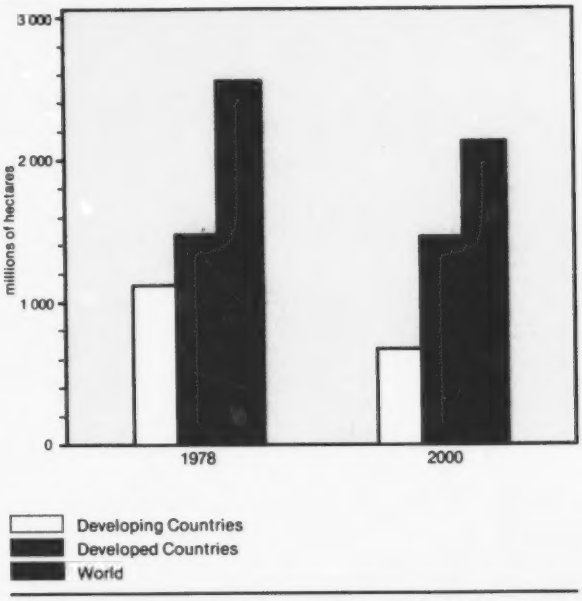
There are some signs in the western industrialized countries that the seriousness of this deforestation is gradually being recognized, but the actions being taken are far from adequate. Even with

Figure 11.2
Actual and Estimated World Production of Aquatic Organisms, 1963-2000



Source: S. Miles, "The changing world: Implications for Canada in the eighties: An environmental perspective", Report prepared for Environment Canada, 1980.

Figure 11.3
Estimates of World Closed Forest[1] Resources, 1978 and 2000



[1] Closed forest includes lands used primarily for forestry and where tree crowns cover 80 per cent of the area, except for the USA, where the term excludes forestland incapable of producing more than 1.4 cubic metres of industrial wood per hectare per year, and Canada, where the term excludes land incapable of producing stands of trees 10 cm in diameter or larger on 10 per cent or more of the area.

Source: U.S. Council on Environmental Quality and Department of State, *The Global 2000 Report to the President*, Volume Two, 1980.

increases of forest cover in western Europe in the next 20 years, needs will outstrip supply and require more imports from North America and the developing countries.[8]

The real problem will arise in the developing countries, which have always depended heavily on wood for cooking and heating fuel. This dependency has become more pronounced as escalating oil prices have made it more difficult to purchase kerosene. In 1978, more than 1.2 billion cubic metres of charcoal and firewood were burned in developing countries — almost 50 per cent of the estimated total world forest harvest.[6] The use of wood as fuel often competes directly with the pressure to export timber to help finance foreign debts. The absence of reforestation programs may lead to massive soil erosion, which in turn affects the quality and availability of water and adds to flooding of agricultural lands and settlements downstream.

Approximately 20 per cent of Canada's land mass is productive forest, and forestry is the country's largest industry. About 160 million cubic metres of wood are harvested annually, contributing nearly 20 per cent to the total value of exports in 1980. In fact, Canada claims more than 30 per cent of the world export market for lumber, wood pulp and paper.[4]

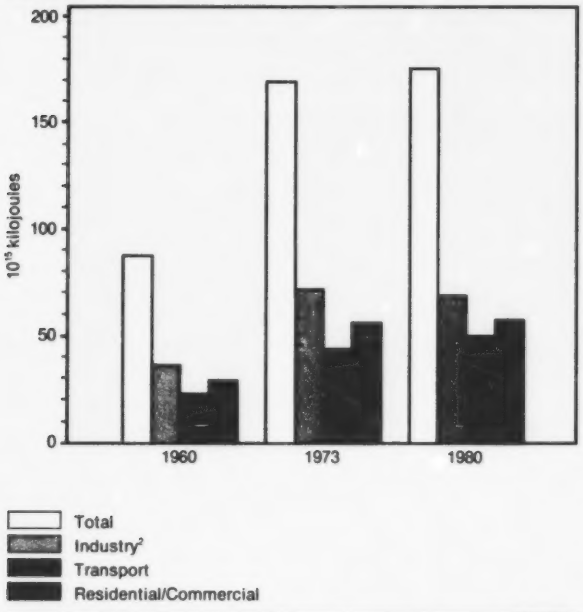
With the continuing decline in the world forest cover and the increasing need for forest products, there will be pressure on Canada to increase its output. Co-ordinated long-term planning will be necessary if yields are to be sustained or increased.

Energy Resources

Data concerning energy consumption patterns between 1960 and 1980 in the countries belonging to the Organization for Economic Co-operation and Development (OECD) are shown in Figure 11.4. The figure shows energy consumption by industry, transportation, and residential/commercial sectors in 1960, 1973 and 1980. Annual primary energy consumption in the OECD countries for the three years was 87, 169 and 176 x 10^{15} kJ. Industry consumed roughly 40 per cent of the total while residential/commercial use consumed about 33 per cent and transportation the remainder.

The shares of coal, oil, gas, and electricity used by each of these sectors for the three time periods

Figure 11.4
OECD Primary Energy[1] Consumption, 1960, 1973 and 1980



[1] Primary energy includes bunkers. (Energy conversion: 1 million tonnes of oil equivalent = 46.1872×10^{15} kJ)

[2] Industry sector includes non-energy use.

Source: Organization for Economic Co-operation and Development, *World Energy Outlook* (Paris: OECD, 1982).

is shown in Figure 11.5. For industry, coal as a proportion of all energy consumed decreased from roughly 40 per cent in 1960 to 20 per cent in 1980. Industry's proportional use of oil peaked in 1973 (at about 43 per cent) before falling to 37 per cent in 1980, compared with 30 per cent in 1960. The use of gas and electricity increased proportionately.

The pattern was similar for residential/commercial energy consumption, except that the decrease in the proportion of coal and the increase in the proportion of gas and electricity as energy sources were even more marked. The proportion of oil as an energy source in 1980 was almost the same as it was in 1960, down 10 percentage points from the 1973 figure of 47 per cent.

The world energy outlook is volatile. The 1973 energy crisis led a number of nations to embark on programs to reduce their energy requirements (conservation measures) and their dependency on imported energy supplies. The picture is complicated by oil supply cartels and political instability in some oil-supplying countries. The further development of Canadian hydrocarbon resources (tar sands, coastal waters and the far north) will be governed by both national and international political and economic considerations.

Future trends in patterns of world energy production and consumption are also of considerable interest to environmentalists. One projection of primary energy production from 1970 to 2020[9] is shown in Figure 11.6. The curves show a levelling off and decline in the proportion provided by oil and gas, accompanied by a 400-per cent increase in hydro-electric power, a 400-per cent increase in coal production, and a geometric rise in nuclear-generated electricity. Renewable energy sources develop more slowly but are projected to grow by about 400 per cent between 1972 and 2020.

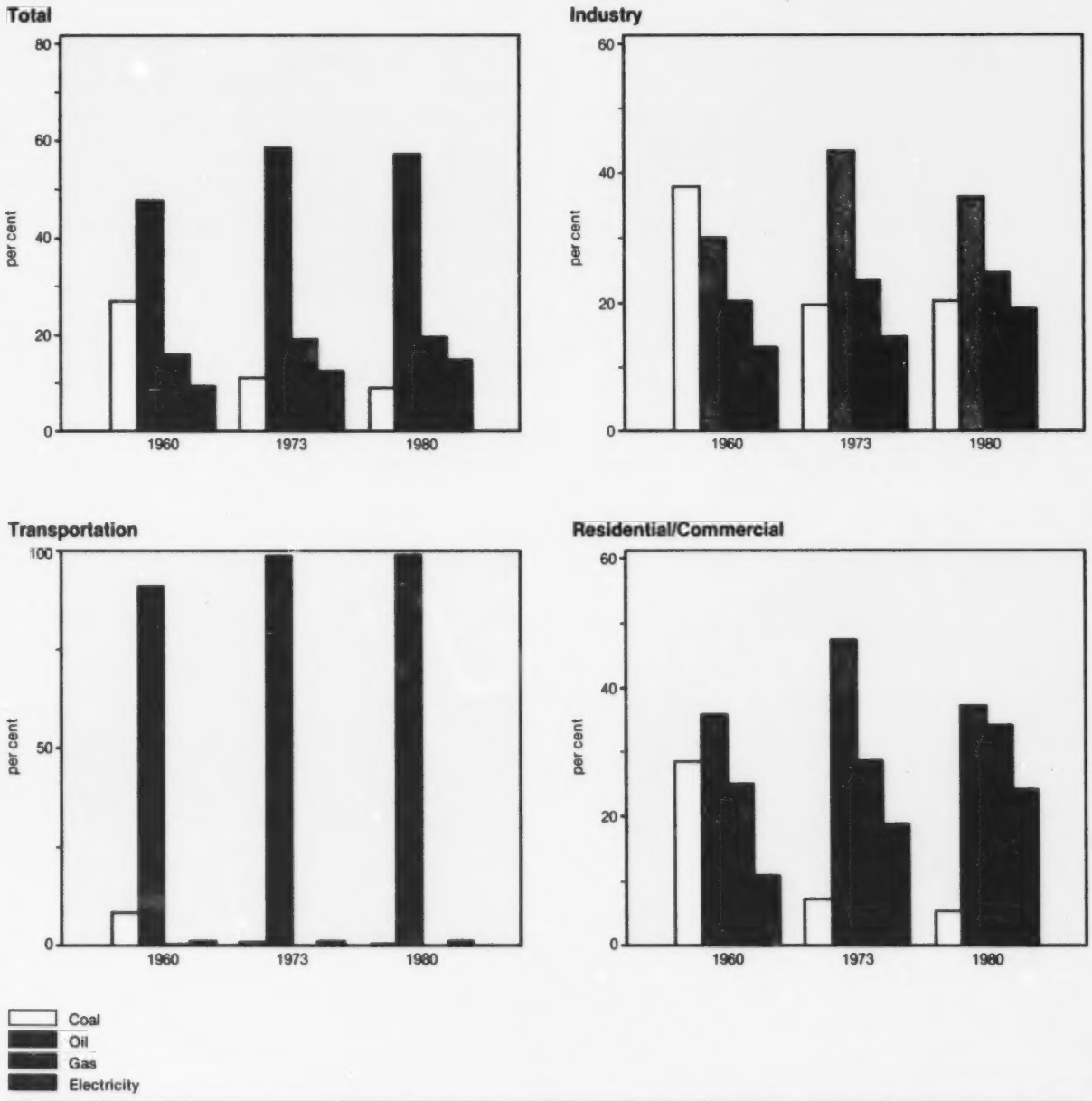
The most notable feature of Figure 11.6 is the rapid rate of increase projected for nuclear energy. Since the preparation of the World Energy Conference Report (1978), several factors have combined to make this particular projection unrealistic. Rising construction costs and reactor malfunctions have caused widespread concern about the viability of nuclear power. This has led to financial difficulties that, coupled with public opposition in many countries, are causing major delays in construction and uncertainty in planning of nuclear power programs.

Projections of annual increases in energy demand, extrapolated from past trends, often fail to account for structural changes and technology (e.g., strides in the efficiency of conventional means of electrical power generation). Extrapolation is a poor guide when one considers that apparently minor annual increases in energy demand tend to compound at an astounding rate, so that a mere 2-per cent annual rise in demand translates into a doubling every 35 years.

At the world level, it has been argued that developing nations will require large amounts of energy in the years ahead to achieve their economic development objectives. The appropriate type and scale of energy supply is a matter of hot debate. Should these countries follow the large-scale energy production systems currently employed in industrial countries? Or should they adopt a strategy of smaller, more environmentally compatible energy sources, which might be more appropriate for community-based economic development?[2]

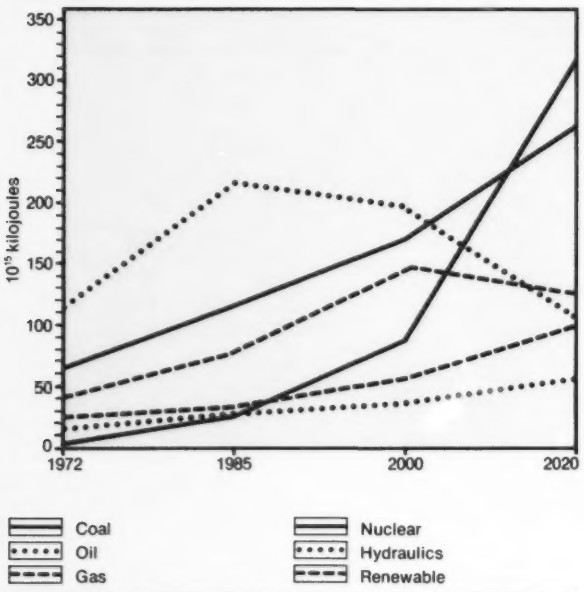
More than a decade after the 1973 oil crisis, there is little consensus about the form that future world energy strategies should take. It is clear, however, that environmentally sound energy development is technically feasible and, to a large degree, economically attractive. In Canada, evolution in the use of renewable energy sources, in energy conservation, and in the development of non-conventional hydrocarbon resources such as tar sands and offshore oil reserves will be guided by public policy, world energy prices, and the ability of local communities to apply emerging technologies to meeting specific energy requirements.

Figure 11.5
Fuel Shares in OECD Primary Energy Consumption, 1960, 1973 and 1980



Source: Organization for Economic Co-operation and Development, *World Energy Outlook* (Paris: OECD, 1982).

Figure 11.6
Potential World Primary Energy Production



Totals for 2000 and 2020 include contributions of 4 and 40 × 10^{15} kJ from unconventional oil and gas.
Source: World Energy Conference, *World Energy: Looking Ahead to 2020* (New York: IPC Scientific and Technical Press, 1978).

THE GLOBAL COMMONS

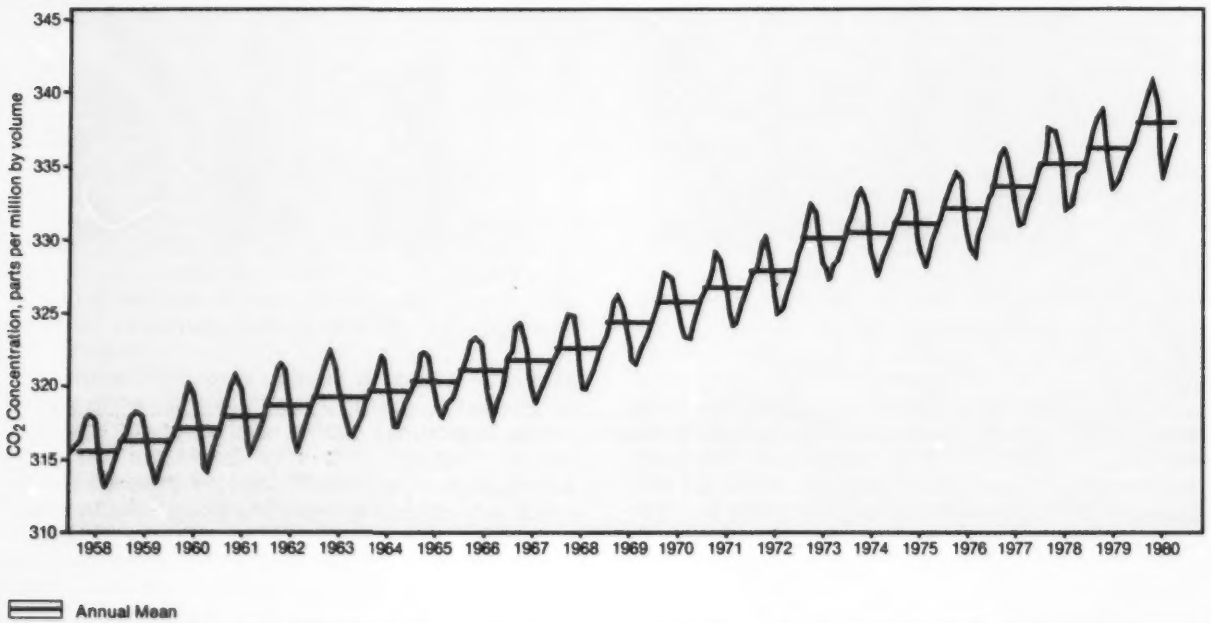
The term global commons refers to those aspects of the environment that are shared among nations: the atmosphere, the seas, and, to a degree, the genetic diversity of the earth's flora and fauna. Changes in the condition of the global commons are particularly difficult to assess because of the scale of monitoring required. In some cases, the extent or existence of change remains speculative; in most instances, the specific consequences of possible changes in the global environment are difficult to predict. International efforts are under way to improve the knowledge base, clarify risks and seek international accords. An understanding of these forces provides necessary background for assessing changes in the environment.

The Atmosphere

Atmospheric composition is changing regionally and globally as a result of unprecedented levels of waste emissions. There are currently two major areas of concern: the increase in the concentration of carbon dioxide in the atmosphere, and the suspected reduction in the protective ozone layer in the earth's stratosphere.

Carbon dioxide (CO_2) concentrations in the atmosphere have increased significantly over the past

Figure 11.7
Monthly Averages of Atmospheric Carbon Dioxide Concentrations at Mauna Loa, Hawaii



Source: United Nations Environment Program, *The World Environment, 1972-1982*, M.W. Holdgate, M. Kassas, and G.S. White, eds. (Dublin: Tycooly International Publications, 1982).

century. Before 1850, CO_2 concentrations were reported in the range of 265 to 290 parts per million (ppm). In 1984, mean levels approached 344 ppm, an increase of as much as 30 per cent over 1850 levels. Figure 11.7 indicates the cyclical but steadily increasing trend in CO_2 concentrations recorded at the Mauna Loa baseline station in Hawaii between 1958 and 1980. Similar upward trends have been recorded at a number of other sites.

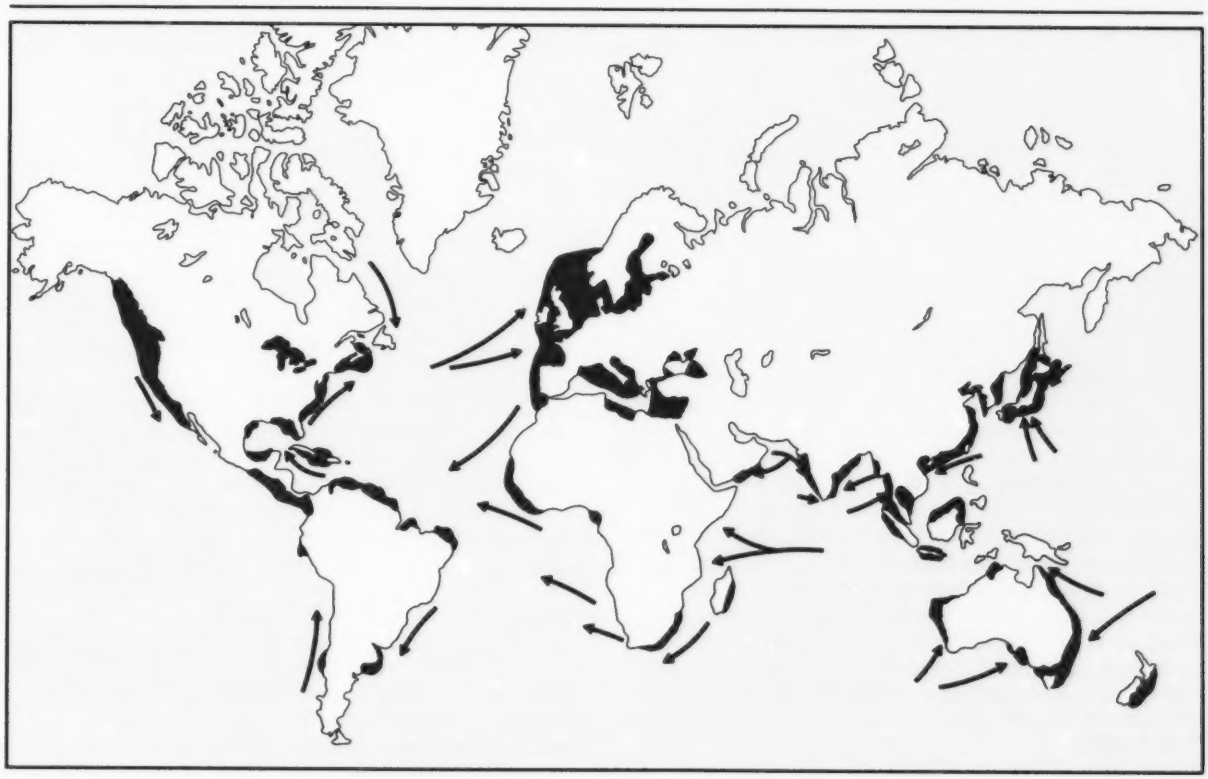
The main factor contributing to the CO_2 build-up is undoubtedly the substantial increase in the annual release of CO_2 into the atmosphere from fossil fuels combustion, cement production, and natural gas flaring. The large-scale clearing of forests, particularly when forests are burned and the soil humus is oxidized, contributes to the CO_2 build-up, both directly and by reducing CO_2 uptake by the world's plant community.

About 50 billion tonnes of carbon dioxide are now released into the atmosphere each year, of which almost half is thought to remain there. The bulk of the remainder is absorbed by the oceans, leaving 10 to 15 per cent unaccounted for. By the year 2020, atmospheric CO_2 levels may be double the 1982 concentration, assuming continued increase at current rates (nearly 2 per cent per annum).

Doubling the carbon dioxide content of the atmosphere could lead to a significant increase in the earth's surface temperature of one to two degrees Celsius. Changes could be considerably greater in the high latitudes of the northern hemisphere (perhaps 7 to 10°C in the arctic winter) and considerably less in the tropics. Such changes would have significant implications for fisheries, forestry and agriculture. Under these conditions, arctic pack ice might melt in summer. It has also been suggested that if warming were significant and persistent enough, it could cause melting of part of the western antarctic ice sheet and a consequent rise in sea levels of five to six metres.[1]

There is inferential evidence that the earth's pro-

Figure 11.8
Marine Pollution Around the World



Source: United Nations Environment Program, *The World Environment, 1972-1982*, M.W. Holdgate, M. Kassas, and G.S. White, eds. (Dublin: Tycooly International Publications, Ltd., 1982).

Table 11.1
Sources of Pollution to World Ocean Regions

Water Discharge or Other Processes or Activities Potentially Causing Contamination	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O
Sewage	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
Petroleum Hydrocarbon (Maritime Transport)	■	■	■	■	■	■	■	■	■	■	■	■			
Petroleum Hydrocarbon (Exploration & Exploitation)		■		■	■			■		■	■	■	■		
Petrochemical Industry		■	■	■					■	■	■				
Mining			■					■		■			■	■	
Radioactive Wastes	■	■	■				■		■	■		■			
Food & Beverage Processing	■	■	■			■				■	■	■	■	■	■
Metal Industries		■	■		■				■	■		■			■
Chemical Industries	■	■	■						■	■					
Pulp & Paper Manufacturing	■			■	■					■			■	■	■
Agricultural Runoff (Pesticides & Fertilizers)			■		■		■	■		■					■
Siltation from Agriculture and Coastal Development						■	■	■			■				
Sea-salt Extraction							■				■				
Thermal Effluents						■	■		■	■	■	■			
Dumping of Sewage Sludge & Dredge Spoils		■							■	■					

A Baltic Sea
B North Sea
C Mediterranean Sea
D Persian Gulf
E West African Areas
F South African Areas
G Indian Ocean Region
H South East Asian Areas
I Japanese Coastal Waters
J North American Areas
K Caribbean Sea
L South West Atlantic Region
M South East Pacific Region
N Australian Areas
O New Zealand Coastal Waters

Source: United Nations Environment Programme, *The World Environment, 1972-1982* (Dublin: Tycooly International Publications, Ltd., 1982).

tective ozone layer is being depleted by the release of chlorofluorocarbons (CFCs) and other chemicals. Again, there are vast uncertainties here, including the fact that detection of changes in the stratospheric ozone layer is still not possible. Estimates of the amount of eventual depletion of the ozone layer are therefore little more than guesses. These estimates were recently revised downwards, from 15 to 25 per cent to 5 to 10 per cent.[5] It is known that increased exposure to ultraviolet light has deleterious effects on humans and other organisms (e.g., increased incidence of skin cancer). Although the dimensions of this problem are still poorly understood, there is sufficient concern that 21 countries recently signed an international convention for the protection of the ozone layer (March 1985).

The Oceans

About 25 billion tonnes of suspended material are deposited annually in the world's oceans, approximately 90 per cent as river effluent. Pollutants entering seawater in these sediments may be concentrated 1 000 or even 100 000 times by bio-accumulation in the food chain.

Table 11.1 shows major sources of pollution for various regions of the world's oceans. Data on concentrations of pollutants in seawater and biota are scarce and rarely permit the establishment of quantitative trends. It is known, however, that most pollutants are concentrated in estuaries and coastal waters. Up to 1982, UNEP had found little change in the concentrations reported by the Food and Agriculture Organization in 1971 (Figure 11.8).

Although much of the world's seawater appears to be relatively free of contaminants, there is still cause for concern. The regions most heavily affected are usually critical habitats for marine fish, mammals and birds. For example, some 60 per cent of the total commercial fish catch in the United States and 97 per cent from the Gulf of Mexico comes from species that depend on estuarine environments. Fish from the coastal areas of landlocked seas contain more than 10 times as much mercury as fish from the open ocean.[5] The sources of this pollution include plastics, paint, paper, chemical industries, agriculture, and

erosion of rocks containing mercury. Polychlorinated biphenyls (PCBs) and DDE (a metabolite of the pesticide DDT) accumulate in fish and marine mammals. High concentrations of these substances have been reported in fish and shellfish caught near industrial centres. Killer whales off the British Columbia coast were recently found to have extremely high levels of DDE and PCBs.

Oil pollution of the seas has both local and global aspects. During the past two decades, the impact of oil spills on seabirds and marine ecosystems has been an issue of widespread concern. Even small spills are hazardous. The 400 tonnes of fuel oil that leaked from a grounded tanker in the Kattegat (Denmark) reportedly resulted in the death of more than 35 000 birds.[5] The combination of oil spills and climatic stress appears to exacerbate the damage. For example, a number of lightly oiled birds were found dead on the Nova Scotia coast following the *Argo Merchant* oil spill off the New England coast in December 1976, during a particularly cold winter.

Table 11.2 indicates the sources of petroleum hydrocarbons entering the ocean between 1969 and 1971. Ignoring natural seeps and atmospheric rainout, some 2 to 4 million tonnes entered the seas each year at that time; marine transportation accounted for roughly half of this amount. Tanker accidents accounted for only 10 per cent of the oil spillage from marine transportation. More recent information in the OECD report, *The State of the Environment 1985*, confirms these estimates at 4 million tonnes per year.

Oil in the oceans becomes well dispersed over a period of time. Data collected by the Integrated Global Ocean Station System Marine Pollution (Petroleum) Monitoring Project confirmed the high frequency of visible oil slicks and tar at sea.*

Table 11.2
Comparison of Estimates of Petroleum Hydrocarbons Entering the Oceans
(millions of tonnes per year)

	Authority		
	SCEP Report[1] (1970)	USCG Impact Statement[2] (1973)	NAS Workshop[3] (1973)
Marine transportation	1.13	1.72	2.133
Offshore oil production	0.20	0.12	0.08
Coastal oil refineries	0.30	—[4]	0.2
Industrial waste	—	1.98	0.3
Municipal waste	0.45	—	0.3
Urban runoff	—	—	0.3
River runoff	—	—	1.6
Subtotal	2.08	3.82	4.913
Natural seeps	?	?	0.6
Atmospheric rainout	9.0	?	0.6
Total	11.08	?	6.113

[1]SCEP: Study of Critical Environment Problems.
[2]USCG: United States Coast Guard.
[3]NAC: National Academy of Sciences, Washington, DC.
[4]No estimate made.
Source: United Nations Environment Programme, *The World Environment, 1972-1982* (Dublin: Tycooly International Publications, Ltd., 1982).

Loss of Genetic Diversity

The genetic diversity of flora and fauna is regarded as a global resource that has widespread benefits, because it provides varieties of plant and animal foodstuffs and medications. This diversity appears to be declining for a number of reasons. In agricultural systems, economic pressures for improved yields account for dwindling genetic diversity in important crops. In 1978, only four varieties of wheat produced 75 per cent of the Canadian wheat crop, almost 75 per cent of the United States potato crop consisted of only four varieties, and the entire U.S. soybean crop was derived from six plants (from one Asian source). Almost all Brazilian coffee trees derive from a single plant. Although world seed banks have been established, any reduction in the genetic diversity of crops increases their vulnerability to major pest and disease outbreaks or changes in climate. Similar concerns have been expressed with respect to livestock. Of the 145 indigenous cattle breeds in Europe and the Mediterranean region, 115 are now threatened with extinction according to the World Conservation Strategy.

Genetic diversity in undomesticated fauna and flora provides potential sources of new foodstuffs and pharmaceuticals. The International Union for the Conservation of Nature and Natural Resources estimates that about 25 000 plant species and over 1 000 vertebrate species are now threatened with extinction. Losses of insects, corals and other invertebrates may be far higher. While worldwide extinction rates cannot now be estimated with any degree of accuracy, it has been suggested that we currently lose species at a rate of one per day — ten times the rate of the last century.

*More than 10 000 visual observations between 1975 and 1978 indicated that the most polluted regions in the northern hemisphere are the Red Sea, the Straits of Malacca, the Mediterranean, the Caribbean, and the South China Sea. In the southern hemisphere, the waters around South Africa may well be the most polluted (38 per cent of the oil transported by sea passes around the Cape of Good Hope). See reference #5.

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INTRODUCTION

Public attitudes can affect the quality of the environment in at least two important ways. First, individuals can mobilize support for particular issues and exert political pressure that causes changes in public environmental policies. Second, public attitudes can affect the way individual members of society act in relation to the environment — the extent to which they practise energy conservation, the care they take to ensure that campfires are extinguished, and so on. Furthermore, public attitudes can apply considerable pressure on the private sector (for example, to change consumer products).

HUMAN VALUES AND SCIENTIFIC ASSESSMENTS

The public's perception of a specific environmental issue is influenced by one or more of several personal factors. Age, sex, education, and personality, along with family composition, income, health status, outdoor interests and past experience with other environmental problems, all affect the way an individual thinks about the environment and its future prospects.

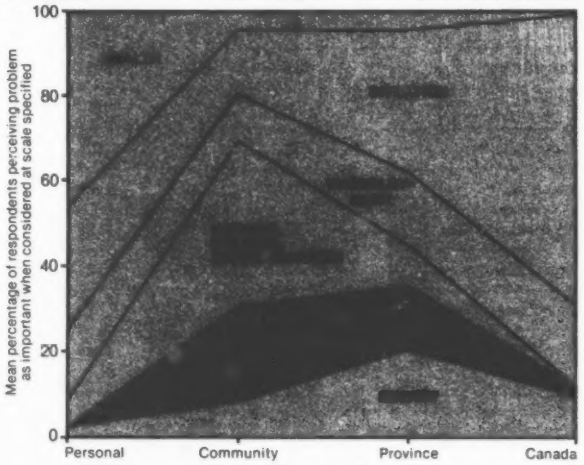
In studying environmental quality, researchers try to minimize the influence of personal views and produce quantitative measurements of conditions. These might be referred to as scientific or objective values. It is not surprising, therefore, that from time to time the public perception of an environmental issue may not accord with objectively measured conditions, and vice versa.

Some information about the environmental perceptions of Canadians is presented here as part of the background to this report. Much of it is based on formal national opinion surveys such as those carried out by CROP, Inc. (*Centre de Recherche sur l'Opinion Publique*) and by the Gallup organization. The interpretation of such surveys is not easy at the best of times, but it is even more difficult to identify regional differences and time trends. Such aspects as the phrasing, order and comparability of questions from one survey to another are important in assessing results.

ENVIRONMENTAL PROBLEMS IN PERSPECTIVE

Environmental concerns always have an organizational context. Some problems are seen as distinctly individual or personal, while others may be community, provincial, national or even global in nature. The relative importance of a number of major societal problems, viewed from a personal, community, provincial or national perspective, is shown in Figure 12.1. This figure suggests that 'environment' is perceived to be most important on a community scale, with the provincial scale not too far behind. Some concerns about health may also have a direct relationship to environmental issues, e.g., toxic substances. The same holds true for several aspects of energy concerns, from exploration for energy resources to consumption of energy and disposal of associated wastes. These relative perceptions change with time and circumstances. For example, a particularly serious environmental accident or event could result in a significant change in attitude, at least for a short period of time.

Figure 12.1
The Relationship of Environmental Concerns to Other Problems in the Perceptions of Canadians[1]



[1] This chart depicts the relative importance of selected issues in the context of individuals' personal concerns, their community, their province or their nation. It is based on a composite of opinion polls conducted in the late 1970s and early '80s.

Source: A. Whyte and I. Burton, "Perceptions of Risks in Canada", in *Living with Risk: Environmental Risk Management in Canada*, I.E.S. Environmental Monograph No. 3 (Toronto: University of Toronto Press, 1982).

THE RELATIVE IMPORTANCE OF ENVIRONMENTAL PROBLEMS

Data concerning the public perception of environmental problems at the national and provincial levels show that water pollution and acid rain head the list (Tables 12.1 and 12.2). The 1982 survey suggests that acid rain was felt to be the most significant environmental problem at the national level, whereas water pollution remained the most significant problem at the provincial level. This change is accounted for by a reduction in the importance of water pollution as perceived by respondents in Ontario and western Canada and an increase in the significance of acid rain in the perceptions of respondents in western Canada.

Table 12.1
Public Perception of Most Important Environmental Problems at National Level

	Western Canada		Ontario		Quebec		Atlantic Canada		Total	
	1981	1982	1981	1982	1981	1982	1981	1982	1981	1982
Sample Size	661	662	501	502	573	597	225	237	1 960	1 998
	%	%	%	%	%	%	%	%	%	%
Water pollution	22	16	23	16	26	23	13	14	22	18
Acid rain	18	24	18	17	14	16	24	24	17	20
Industrial pollution	12	9	6	6	9	5	6	9	8	7
Air pollution	5	9	12	8	10	11	9	14	9	10
Air and water pollution	6	5	5	9	5	6	7	4	6	7
Pollution (unspecified)	4	8	8	10	8	8	7	7	7	9
Destruction of forests	2	1	1	3	4	4	4	4	2	3
Dump sites/chemical dumps	3	4	4	7	1	2	3	4	3	5
Don't know & other	27	24	23	22	24	24	28	19	24	23

Source: CROP Survey Reports, 81-4, 82-2.

Table 12.2
Public Perception of Most Important Environmental Problems at Provincial Level

	Western Canada		Ontario		Quebec		Atlantic Canada		Total	
	1981	1982	1981	1982	1981	1982	1981	1982	1981	1982
Sample Size	661	662	501	502	573	597	225	237	1 960	1 998
	%	%	%	%	%	%	%	%	%	%
Water pollution	26	28	21	25	43	35	11	14	27	27
Acid rain	6	4	27	24	10	9	12	27	15	15
Industrial pollution	10	8	9	6	8	5	5	4	9	6
Air pollution	8	8	11	8	6	9	6	7	8	8
Air and water pollution	7	3	5	7	5	7	3	0	6	5
Pollution (unspecified)	4	8	7	8	8	7	6	17	6	9
Destruction of forests	5	6	1	2	2	4	36	10	6	5
Dump sites/chemical dumps	4	4	5	5	2	2	2	3	4	4
Don't know & other	30	30	14	15	14	21	19	16	18	21

Source: CROP Survey Reports, 81-4, 82-2.

Although the overall ranking of problems at the provincial level remained essentially the same between 1981 and 1982, there was a noticeable shift in some areas. Respondents in Quebec showed a decreased concern about water pollution and a corresponding increase in the 'don't know and other' category. Respondents in Atlantic Canada indicated a marked increase in the importance of acid rain and pollution (unspecified) and, at the same time, a marked decrease in the relative importance of the destruction of forests. Respondents in Quebec considered water pollution to be the most important environmental problem at both the national and the provincial level.

POLLUTION AS A SUB-SET OF ENVIRONMENTAL PROBLEMS

Data concerning the perceived relative importance of several forms of pollution at the local or neighbourhood level are summarized in Figure 12.2. The data indicate some increase in the perceived importance of air and water pollution and a decrease in the importance of noise pollution. The increase with respect to air pollution is largely a reflection of the change in perception by respondents in Atlantic Canada, whereas the increase in importance of water pollution reflects the changing views of respondents in Quebec and Ontario. The decrease in concern about noise pollution was observed everywhere except Atlantic Canada.

Data on perceived changes in pollution levels are shown in Figure 12.3. At a national or provincial level, well over 50 per cent of respondents thought that pollution levels had increased. On the other hand, from a neighbourhood perspective, about 50 per cent thought that pollution levels remained the same. Over a 4-year period, the percentage that perceived a decrease in pollution levels ranged, overall, from 5 to 6 per cent in 1981 to a high of 10 to 12 per cent in 1983, with the 1984 figures showing a range of 9 to 11 per cent.

PERCEPTIONS ABOUT SPECIFIC ENVIRONMENTAL ISSUES

Many environmental issues have received public attention in recent years. A few are selected here for specific examination. They are energy and nuclear power generation, acid rain, toxic substances, rare and endangered species, water quality, and forest management.

Energy and Nuclear Power Generation

Public perceptions of an existing energy crisis and a probable shortage of energy in five years' time are summarized in Table 12.3. In 1979, 1980 and 1982, most Canadians felt that there was not an existing energy crisis. The belief that there will be no real shortage in five years increased from 43 per cent in 1979 to 63 per cent in 1982.

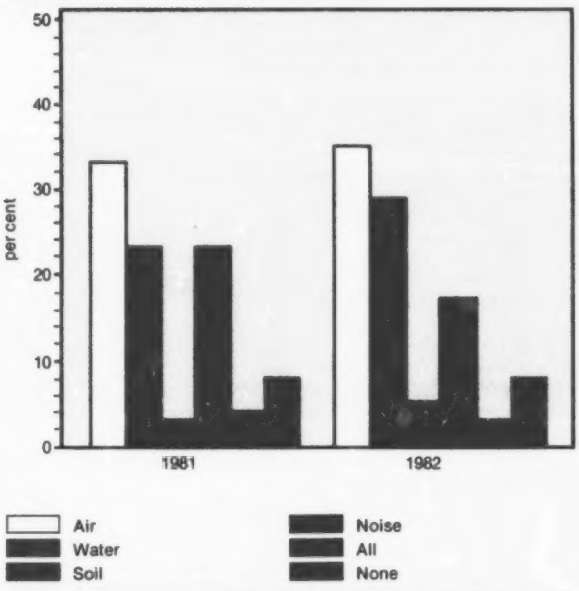
When the 1982 data are examined from a regional point of view (Table 12.4), it appears that roughly half the respondents in the Atlantic area perceived an existing energy crisis. Respondents in British Columbia were the most likely to think that there would not be a real shortage over the next five years.

Data concerning attitudes to nuclear power generation in Canada are summarized in Figure 12.4. These surveys covered the period between September 1976 and November 1982, which included such events as the Three Mile Island nuclear reactor accident at Harrisburg, Pennsylvania in March 1979. The trend in public attitudes is against nuclear power generation. Support for increasing nuclear power generation declined from 41 per cent in 1976 to 20 per cent in 1982. The percentage favouring no further development of nuclear power increased from 20 per cent in 1976 to 35 per cent in 1982. The portion of respondents that would stop generation of nuclear power increased from 14 per cent in 1976 to 31 per cent in 1982.

Acid Rain

Is acid rain the most serious environmental problem in Canada? The results are summarized in Figure 12.5a. This issue has received a great deal of

Figure 12.2
Perception of Relative Importance of Air, Water, Soil and Noise Pollution at the Neighbourhood Level



Source: CROP Survey Reports, 81-1, 82-1.

Table 12.3
Public Perception of an Energy Crisis in Canada, 1979-1982

	% of sample			
	1979	1980	1981	1982
(a) Is there an energy crisis in Canada today?				
Yes	40	34	47	35
No	54	58	46	61
Don't know	6	7	7	5
(b) Will there be a shortage of energy in 5 years' time?				
Very serious shortage	12	10	14	7
Quite serious shortage	37	30	26	25
No real shortage	43	52	51	63
Don't know	9	9	9	6

Source: Gallup Report, 24 July 1982.

Table 12.4
Regional Analysis of Public Perception of an Energy Crisis in Canada, 1982

	% of sample				
	British Columbia	Prairies	Ontario	Quebec	Atlantic
(a) Is there an energy crisis in Canada today?					
Yes	24	37	28	41	49
No	74	60	65	54	48
Don't know	1	3	7	5	3
(b) Will there be a shortage of energy in 5 years' time?					
Very serious shortage	6	5	5	8	15
Quite serious shortage	17	33	21	29	19
No real shortage	76	57	67	56	61
Don't know	1	6	7	7	5

Source: Gallup Report, 24 July 1982.

Table 12.5
Public Perception of Water Quality in the Great Lakes

	All Respondents	Owners	Users	Non-users
1. Satisfaction with existing quality				
Sample size	3 066	461	1 172	1 433
% response				
Satisfied	31.4	43.6	29.6	29.0
Neither satisfied nor dissatisfied	5.9	5.9	5.9	6.0
Dissatisfied	53.2	44.6	61.6	49.0
No opinion	9.5	5.9	2.9	16.0
2. Perception of change in quality				
Sample size	3 056	461	1 170	1425
% response				
Yes	70.2	76.5	79.5	60.6
No	12.8	14.8	10.7	13.8
Don't know	17.0	8.7	9.8	25.6
3. Direction of change				
Sample size	2 236	381	993	862
% response				
Better	22.6	24.4	26.0	21.2
Worse	49.0	33.3	42.6	52.3
No change	4.2	3.7	5.6	3.9
Don't know	24.2	38.6	25.8	22.6

Source: Environment Canada, "Public Perceptions of Water Quality in the Great Lakes" (Ottawa: Inland Waters Directorate, 1981).

media coverage, especially in the context of negotiations between Canada and the United States, and was perceived as one of the most serious environmental problems by more than 75 per cent of respondents. The overall percentage changed little between 1981 and 1984, although there was a gradual increase in perception of the seriousness of the problem by respondents in Quebec.

Toxic Substances

Respondents were asked whether there was enough government regulation to protect the environment from toxic materials. The results are shown in Figure 12.5b. More than 75 per cent of all respondents felt that existing regulations were inadequate. There was a marked increase in the percentage of respondents in Atlantic Canada supporting this view in the 1982 survey.

Rare and Endangered Species

Does government give adequate protection to rare and endangered species? The results are presented in Figure 12.5c. Overall, the percentage agreeing that current protective measures are adequate was slightly greater than the percentage disagreeing. The only detectable trend was in Atlantic Canada, where there was a noticeable shift towards agreement that government is doing enough.

In co-operation with the Canadian Wildlife Service, Statistics Canada conducted a survey of 100 000 Canadians in 1981 to assess the importance of wildlife to Canadians. When asked to indicate how important preserving endangered species was to them, 82 per cent of respondents answered that it was very or fairly important.

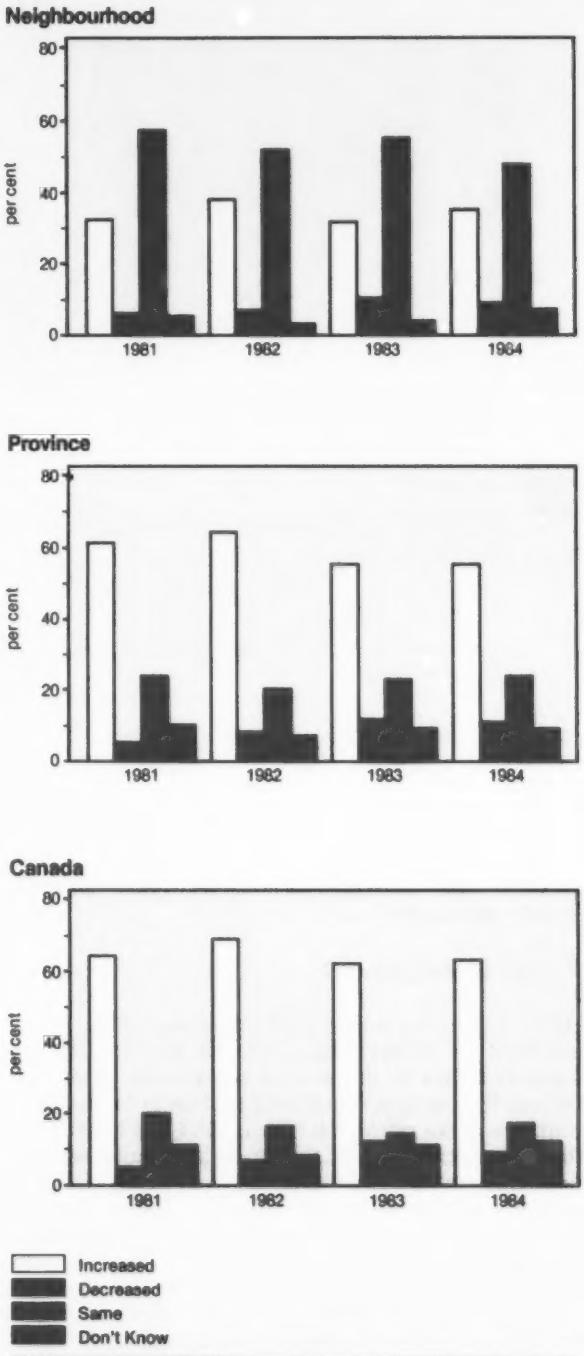
Water Quality

A telephone survey conducted in 1978 for Environment Canada sought to determine public perceptions and attitudes towards water quality and water quality management in the Great Lakes from Georgian Bay through Lake Ontario. Data from this survey are summarized in Table 12.5. The data show that there are differences in perception among owners of shore property, recreational users, and non-users of the water.

Slightly more than half the respondents were dissatisfied with existing water quality. Some 70 per cent thought that there had been a change in quality, and 49 per cent of those believed that the change had been for the worse. Owners were almost equally divided between satisfaction and dissatisfaction with existing water quality. Over three-quarters of the owners perceived that there had been some change in quality; 33 per cent thought it was for the worse, and 24 per cent perceived an improvement.

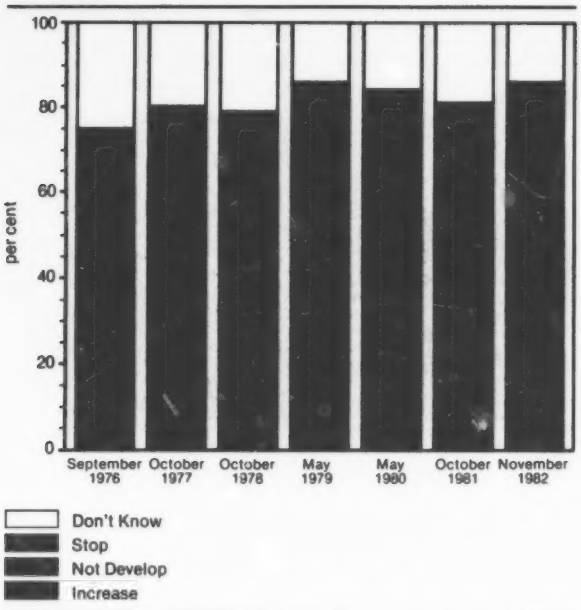
Among the users, almost 62 per cent were dis-

Figure 12.3
Canadian Public Perception that the Level of Pollution has Increased or Decreased in Canada, Their Province, and Their Neighbourhood over the Past Two Years



Source: CROP Survey Reports, 81-1, 82-1, 83-2, 84-1.

Figure 12.4
Attitude to Nuclear Power Generation in Canada, 1976-1982



Source: Gallup Polls for dates cited.

Figure 12.5a
Canadian Public Awareness of Acid Rain as the Most Serious Environmental Problem

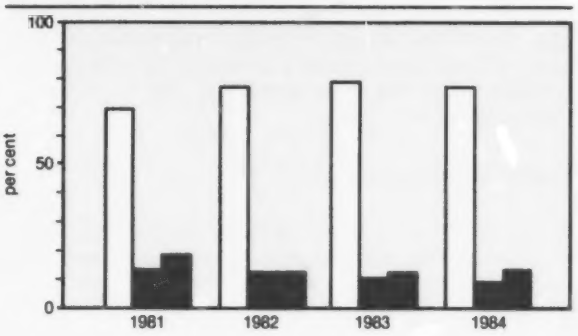


Figure 12.5b
Canadian Public Perception: There is not enough government regulation to protect the environment from toxic materials.

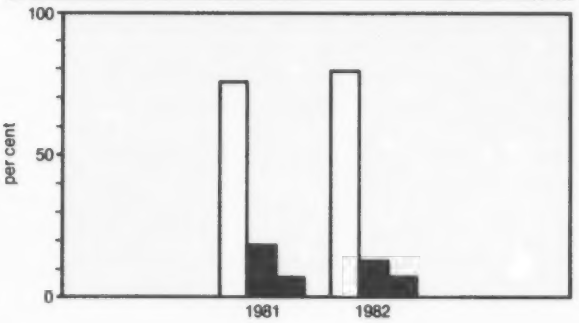
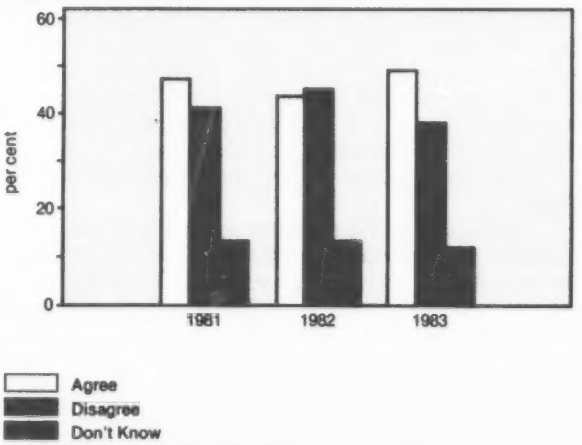


Figure 12.5c
Canadian Public Perception: Government is doing enough to protect rare and endangered species from extinction.



Source: CROP Survey Reports, 81-1, 82-2, 83-2, 84-1.

satisfied, with 80 per cent perceiving change and 43 per cent believing that water quality was worse. Nearly 50 per cent of non-users expressed dissatisfaction with existing water quality, 61 per cent thought changes had occurred, and 52 per cent felt that quality was worse.

Forest Management

Data concerning public attitudes towards the management of forest resources are summarized in Table 12.6. Overall, 90 per cent of respondents did not believe that companies should be free to harvest the forests without government regulation, but fewer than half (38 per cent) felt that forests should not be exploited economically at all. In Quebec, only 22 per cent agreed with this view. Overall, 57 per cent of respondents agreed that chemicals such as pesticides are necessary for taking care of forests. This view was expressed most strongly by respondents in Quebec (by a two-to-one majority) and most weakly in Atlantic Canada, where the response was equally divided. Most respondents (66 per cent) agreed that more trees have been cut down than planted in recent years.

Table 12.6
Public Attitudes Towards the Management of Forest Resources

	Western Canada	Ontario	Quebec	Atlantic Canada	Total
Sample Size	661	501	573	225	1960
	% of sample				
1. Companies should be free to harvest forests without government regulation.					
Agree	7	11	5	17	9
Disagree	92	88	92	83	90
Don't know	1	2	2	0	1
2. Chemicals, such as pesticides, are necessary for taking care of forests.					
Agree	59	53	64	49	57
Disagree	38	42	32	50	39
Don't know	3	4	3	2	3
3. In recent years, more trees were cut down compared to the number of trees planted.					
Agree	56	66	72	83	66
Disagree	27	23	18	14	22
Don't know	16	11	11	3	12
4. The forests should not be exploited economically at all.					
Agree	37	48	22	45	38
Disagree	58	49	75	53	58
Don't know	4	3	3	1	3

Source: CROP Survey Report, 81-4.

Table 12.7
Changing Coverage of Environmental Topics in Canadian Newspapers, 1977-1984

	Coverage (number of lines as % of total[1])							
Topic[6]	1977[2]	1978[5]	1979[5]	1980[5]	1981[5]	1982[5]	1983[3]	1984[4]
All Environment	5.5	4	4	4.5	5.5	4.5	7	7
Waste Control	11	8	10	18	22	16	17	17
Water Pollution	20	18	22	17	18	16	21	16
Air Pollution	4	7	15	13	17	14	17	22
Water Use	14	10	6	6	7	9	6	5
Forests	14	12	9	7	6	14	12	8
Environmental Health	9	21	18	21	14	9	7	5
Fish & Wildlife Conservation	6	6	5	8	5	9	9	18
Land Use & Recreation	12	12	8	6	8	8	6	4
Environment (general)	8	6	6	4	4	4	5	5

[1]For all environment, relative to coverage for all categories; for specific topics, relative to coverage for environment category.
[2]1977 data reflect averages of last two reports because of different classification of topics in first report.
[3]1983 data reflect second half of 1983.
[4]1984 data reflect first half of 1984.
[5]Data for all other years reflect averages for the whole year.
[6]For specific topics, the averages were rounded to nearest whole number.
Source: Canadian Trend Reports, 1977-1984.

PRINT MEDIA COVERAGE OF THE ENVIRONMENT

One way of bringing environmental issues to the attention of the public is through the news media. Coverage can take the form of specific news or feature items, investigative reporting, or editorial comment, and can be carried by television, radio, magazines or newspapers. The most systematic and comprehensive analysis of Canadian media coverage is that provided by *Canadian Trend Report*.* These reports cover many topics and are based on content analysis of 150 newspapers across Canada. Each article is assigned to a specific topic within a major category, and coverage is gauged by the amount of space, as measured by the number of lines, devoted to the article.

The coverage of environmental topics in Canadian newspapers during the period 1977 to 1984 is summarized in Table 12.7. In relation to other major categories (e.g., employment and labour, business and economics, health, energy), environment steadily received between 4 and 5.5 per cent of the total amount of space until 1982. In 1983 and 1984, the figure increased to 7 per cent.

Among environment issues, water pollution has consistently been at or near the top of the list, but over the years there has been a rise in the coverage of air pollution and, by 1984, it was the most frequently covered topic. Coverage of waste control rose sharply in 1980 and 1981 and has remained near the top. Environmental health, a subject of keen interest between 1978 and 1980, now seems to be tapering off. Forests, land use and recreation received substantial coverage at the beginning of the period and decreased later, although forest issues rebounded in 1982. Fish and wildlife conservation issues received a sudden and major increase in attention in 1984.

RECENT TRENDS IN PUBLIC PERCEPTION

Although the issues of water and air pollution, toxic substances and acid rain remain high on the list of public concerns, there appears to be a shift in public attitudes on environmental matters. *Canadian Trend Report* for fall 1984 and summer 1985 notes that public attitudes are reflecting a desire for more, rather than less, government regulation and show an increasing awareness of the long-term aspect and broad scope of environmental issues.

Another relatively new shift in public attitudes is the strengthening of linkages between the environment and the economy. The *Canadian Trend Report* noted in 1984 that it is now more common for economic arguments to be marshalled in favour of, rather than against, tougher environmental standards. There is also an increased tendency to treat economic and social concerns from a long-term perspective and as interrelated. This negates a conventional argument that environmental issues are frills easily over-ridden by job-creating economic concerns. Public opinion statistics from a June 1985 CROP survey support this in that 82 per cent of Canadians agreed, either somewhat or strongly, that the Canadian economy is highly dependent on the state of the environment. It also showed that 94 per cent of Canadians agreed, strongly (64 per cent) or somewhat (30 per cent), that every major economic project should be proven environmentally sound before it can go ahead.

Decima Research findings in the summer of 1985 showed that 6 Canadians in 10 continue to agree that more should be done to protect the environment even if jobs are lost in the process. In the summer of 1984, Decima reported that most Canadians (over 80 per cent) were unconvinced that environmental laws should be relaxed in order to achieve economic growth.

The *Canadian Trend Report* also sees an evolution of environmental values — for example, a shift from remedial to preventive control by government and a growing appreciation of the relationship between environmental and personal health.

**Canadian Trend Report* is based on content analysis of Canadian newspapers and, therefore, reflects public opinion in a more indirect manner than data obtained from opinion polls.

Comments on the Report

We would very much appreciate your comments on this report. Your suggestions will be taken into account in the development of future reports.

Please address comments or requests for further information to:

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